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WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G01B 11/275

A1

(11) International Publication Number: WO 00/70304

(43) International Publication Date: 23 November 2000 (23.11.00)

(21) International Application Number: PCT/US00/13279

(22) International Filing Date: 15 May 2000 (15.05.00)

(30) Priority Data: 09/312,788 17 May 1999 (17.05.99) US

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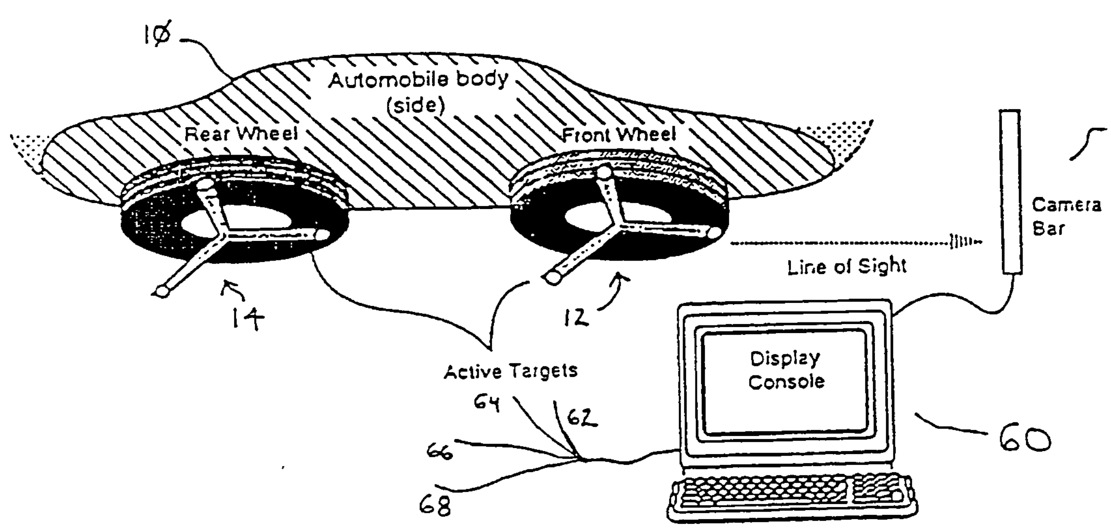
(81) Designated States: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: ACTIVE TARGET WHEEL ALIGNER



(57) Abstract

Apparatus and method for determining vehicle wheel alignment parameters and suspension system condition. Wheel targets including electromagnetic radiation emitters emit pulses in timed sequence. A camera boom having an electromagnetic sensor head thereon detects the pulses. A processor receives from the camera head assembly signals that pertain to the relative positions of the emitters. The processor determines the relative angular coordinates of each emitter and therefrom determines the position of the wheel targets. Wheel alignment parameters and/or the condition of the suspension system may be displayed on a display console.

ACTIVE TARGET WHEEL ALIGNER

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is within the field of wheel aligners. More particularly, this invention is within the arena of optical methods and apparatus for measuring vehicle wheel alignment and detecting suspension system damage.

BRIEF DESCRIPTION OF THE PRIOR ART

Today, as in the past, automotive engineers and car manufacturers are working to meet the demands and standards of the automobile industry. Most standards are established out of environmental, economical, and/or safety considerations. Wheel alignment and vehicle suspension directly affect the efficiency and safety of all motor vehicles, from passenger cars to trucks and busses.

A large number of devices exist for measuring vehicle wheel alignment. Recently, wheel aligners with optical technology have been developed. Examples of wheel aligners that utilize optical technology are disclosed in USPN 5,724,743, USPN 5,535,522, USPN 5,675,515, and USPN 5,657,408. While the optical wheel aligners disclosed in these patents may, in some respects, be easier to utilize than their predecessors, they include delicate and sensitive components that must be handled carefully, often in an environment that is adverse to optical instrumentation. For example, the devices disclosed in both USPN 5,535,522 and 5,675,515 include video cameras that view targets mounted on vehicle wheels. The video cameras provide signals that correspond to images on the targets. The signal-images are processed and analyzed. It is important, therefore, that the wheel targets, and the space between the wheel targets and the camera, remain unadulterated. Whether measuring the wheel alignment of a passenger car, truck, or bus, maintaining such conditions in an automotive repair or wheel alignment shop requires continuous effort. Also, in some instances it is not easy to ascertain whether such conditions are satisfied.

Other prior art optical wheel aligners include delicate and bulky components that require careful manipulation. For example, USPN 5,675,408, discloses an optical wheel alignment system that includes a plurality of laser light sources for attachment to vehicle wheels and rotation therewith.

It is desirable to have a wheel aligner that has the advantages of the prior art optical wheel aligners but does not have the encumbrances discussed above. It is also desirable to provide a device through which the process of measuring wheel alignment may be expedited, e.g., some measurements performed as each wheel clamp is mounted.

Therefore, an advantage of this invention is providing a vehicle wheel alignment apparatus that is rugged and operates well in a coarse environment.

A further advantage of this invention is providing a vehicle wheel alignment apparatus that is lightweight and easy to handle, and has very few delicate components.

Another advantage of this invention is providing a vehicle wheel alignment apparatus that has light and rugged wheel clamp assemblies that are easily and quickly mounted on the wheels of a vehicle.

Yet another advantage of this invention is providing a vehicle wheel alignment method that does not require a complicated or delicate set up procedure and requires minimal effort to maintain in operational condition.

Still another advantage of this invention is providing a vehicle wheel alignment method and apparatus that performs run-out compensation as the wheel clamps are mounted.

A further advantage of this invention is providing a vehicle wheel alignment apparatus that eliminates the need to move the camera head between the wheels to measure setback.

Yet another advantage of this invention is providing a vehicle wheel alignment apparatus that is usable with vehicles such as trucks and buses with three or more axles and is operable across a wide range of wheel base dimensions.

Yet another advantage of this invention is providing a vehicle wheel alignment apparatus that is easy to manufacture and has a minimal number of precision elements to be calibrated.

Yet another advantage of this invention is providing an apparatus and method that ascertains and displays the condition of suspension system components.

SUMMARY OF THE INVENTION

According to various aspects of the invention, an active target wheel aligner preferably includes an electromagnetic radiation sensor for receiving electromagnetic radiation signals from a plurality of electromagnetic radiation emitters associated with a wheel clamp. The active target wheel aligner includes a processor for receiving signals from the sensor and calculating wheel position and

alignment parameters and determining whether the suspension system has worn or damaged components (collectively, wheel position and stability parameters).

In a further aspect of the invention, each emitter is individually activated for a short period of time. An activated emitter produces a pulse of electromagnetic radiation that is easily detected by the sensor. A processor receives a corresponding signal from the sensor and correlates a characteristic of the received signal, such as the time of receipt of the signal, with a particular emitter.

In particular, the apparatus for measuring vehicle wheel alignment of the present invention preferably comprises wheel clamps for providing signals to an electromagnetic radiation sensor head which provides signals to a data processor. Preferably, the wheel clamps are securable to the wheels of a vehicle and have a plurality of electromagnetic radiation emitters affixed thereto in a predetermined spatial configuration. The electromagnetic radiation sensor head receives signals from the plurality of emitters and responsively provides signals corresponding to the relative positions of the emitters. The processor receives the signals and, based upon the predetermined spacial configuration and relative positions of the emitters, calculates wheel alignment parameters and ascertains whether suspension system components are worn or damaged. Preferably, the apparatus of the present invention further comprises a display for displaying wheel alignment parameters and the condition of suspension system components.

The wheel alignment camera preferably includes a plurality of receptors comprised of groups of linearly-adjacent pixel elements for receiving electromagnetic radiation and for providing signals that correspond to electromagnetic radiation intensity. The signals provided by the pixels correspond to the relative positions of the electromagnetic radiation emitters. Preferably, a non-transparent light shield having a plurality of apertures formed therein is positioned in proximity to at least one pixel group and is oriented substantially perpendicular to the group of linearly adjacent pixels.

The preferred emitters emit light in the infra-red spectrum, in a pulsed sequence, so that each emitter operates in sequence at a predetermined time, permitting the receiving apparatus to determine which emitter produced the light that the camera received.

BRIEF DESCRIPTION OF THE DRAWINGS

In describing a preferred embodiment of the present invention, reference is made to accompanying drawings, wherein:

Figure 1 is an illustration of a wheel aligner apparatus in one embodiment of the present invention.

Figure 2 is an illustration of a vehicle wheel and associated wheel clamp and wheel target according to an embodiment of the present invention.

Figure 3 is a plan view of the apparatus of Figure 2.

Figure 4 is a side view of the apparatus of Figure 2.

Figure 5 is a plan representation of an exemplary measurement system implementing the targets shown in Figure 2.

Figure 6 is a plan representation highlighting several aspects of the measurement system of Figure 5.

Figure 7 is an illustration of a camera bar assembly of Figure 5.

Figure 8 is an illustration of part of a linear camera within the camera bar of Figure 7.

Figures 9a and 9b illustrate the camera bar slot arrangements of Figure 7.

Figure 10 is an illustration of a display format provided by the control and display console of the present invention.

Figure 11 is an illustration of a two dimensional active pixel sensor array of another embodiment of the present invention.

Figure 12 is an illustration of a preferred relationship between a wheel and a wheel clamping device and wheel target of one embodiment of the present invention.

Figure 13 is a diagram illustrating a fixed coordinate system for referencing position and attitude of a vehicle wheel in accordance with the present invention.

Figure 14 is a diagram illustrating geometric characteristics of a vehicle wheel as the vehicle is rolled from a first position to a second position in accordance with the preferred embodiment.

Figure 15 is a diagram illustrating the roll angle of the vehicle wheel of Figure 14.

Figures 16(a) through 16(c) are vector diagrams illustrating wheel parameters measured by one embodiment of the present invention.

Figure 17 is a vector diagram illustrating wheel parameters determined by one embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiment of a wheel aligner according to the present invention is illustrated in Figure 1. The apparatus disclosed therein senses the positions of wheel targets and calculates and displays wheel alignment parameters and may also indicate whether components within the suspension system are worn, broken, bent, or damaged.

As shown in Figure 1, targets 12 and 14 are associated with the front and rear wheels, respectively, on the right side of vehicle 10. Preferably, each target is electromagnetically active. A camera bar assembly 30 is positioned in front of vehicle 10. Corresponding front-left active target 16 and rear-left active target 18, not shown, are associated with the wheels on the left side of vehicle 10. Preferably, when camera bar assembly 30 is in its preferred position, active targets 12, 14, 16, and 18 are within its line of "sight". It will be understood that assembly 30 is not ordinarily attached to vehicle 10.

To obtain wheel alignment measurements and/or ascertain the condition of components within the suspension system, one active target is affixed to each vehicle wheel, as described below. An electromagnetic sensor head associated with assembly 30 senses electromagnetic radiation signals from the active targets and provides signals to a control unit. The signals correspond to the location of the active targets.

In the present embodiment, camera bar 30 is situated in front of (or in alternate embodiments, above or behind) vehicle 10, and linear camera units within camera bar assembly 30 provide signals to a control and display console 60. Camera bar assembly 30 may also be situated orthogonally, overhead, or below the vehicle. Control and display console 60 determines the relative position of each active target and its associated wheel. Console 60 includes a data processing unit and a graphic display screen.

Control and display console 60 receives data from camera bar assembly 30 and calculates and displays alignment parameters. The preferred embodiment of the present invention may measure, calculate, and display the camber and caster of a wheel, the thrust line, geometric center line, steering axis, individual toe, offset, setback, steering axis inclination, thrust angle and other parameters well known in the art of vehicle alignment. Additional parameters not mentioned may also be obtained from control and display console 60.

Control and display console 60 may also be programmed to detect symptoms of damaged suspension components such as a bent tie rod or loose ball joint. For example, an excessive toe-in

or toe-out measurement is indicative of a bent tie rod and an unstable or uncertain toe measurement is indicative of a loose ball joint.

The present invention, as described below, may ascertain the condition or reliability of other vehicle components or systems not mentioned above.

Control and Display Console 60

Control and display console 60 preferably includes a data processing unit, such as a programmable computer, and a graphic display screen. In the preferred embodiment of the invention, control and display console 60 includes a personal computer with a keyboard, a printer, and a touch screen display. The computer is programmed to receive data signals from the camera bar and calculate wheel alignment parameters based upon determined positions of the active targets. The computer may provide activation signals to the active targets or may be programmed to correlate some other characteristic of each received signal with a particular emitter.

In an alternative embodiment the processing unit may be comprised of a dedicated processor, memory, and user interface.

Wheel Targets

In keeping with the invention, the wheel targets include a plurality of single-point electromagnetic radiation sources arranged in a predetermined configuration.

As shown in Figures 2-4, in the preferred embodiment, each wheel target is attached to a vehicle wheel by means of a single wheel clamp assembly 20. As best seen in Figure 2, a wheel target 12 may consist of a plurality of target legs extending outward from target center 44. In the preferred embodiment, a wheel target includes three target legs 46, 48, and 50 extending outward in three directions 120° apart. Other wheel target configurations may also be used. For example, the target legs may be of different lengths or may be curved instead of straight. A wheel target may also be comprised of a single target leg or may be generally disk shaped.

A plurality of electromagnetic emitters are associated with each wheel target for providing electromagnetic radiation signals. Three or more emitters may be associated with each wheel target. In the presently-preferred embodiment, one emitter 52 is affixed to the outer end of each target leg, for a total of three emitters per wheel target. The target emitters may be light emitting diodes (LEDs) or any other component capable of emitting a pulsed or modulated or otherwise identifiable electromagnetic radiation signal (hereinafter "light signal"). In the presently-preferred embodiment,

emitters 52a-c are infrared LEDs embedded within the target legs so as not to protrude and be susceptible to damage. In this embodiment, emitters 52 are powered and controlled by control and display console 60 via power cords 62, 64, 66, and 68 (Figure 1). The emitters are pulsed consecutively under control of the control and display console 60. Other techniques may be substituted to correlate received signals with the emitters that produced them. For example, the emitters may be uniquely identified through the use of, for each emitter, a distinct wavelength of light, a distinct modulation frequency, or an emitter signature signal. As explained more fully below, the data processing unit within control and display console 60 is programmed to correlate signals received from camera bar assembly 60 with the particular emitters from which the signals came.

In another embodiment, the emitters are powered by batteries that may be encased within or attached to the wheel targets or wheel clamps. In this embodiment, the emitters are free running and are not connected to control and display console 60 via power cords 62, 64, 66, and 68. The emitter/battery assembly of this embodiment may further include a switch that may be manually activated or activated by control and display console 60 via an electromagnetic (such as infrared radiation), sonic, or other type of signal.

Camera Bar 30

Preferably, a durable and transportable camera bar assembly is provided for receiving pulsed or modulated electromagnetic radiation signals from any one or several of the wheel targets and for providing output signals in response thereto. In the preferred embodiment, the camera bar assembly 30 is similar to the camera of the Wolf measurement system, manufactured by Brewco™ of Central City, Kentucky. The Wolf measurement system is disclosed in U.S. Patent Application Serial No. 09/029,139, entitled "Measuring Device Primarily for Use with Vehicles," filed March 9, 1998 and is incorporated herein by reference. The camera bar is preferably a Flashpoint™ sensor, manufactured by Image Guided Technologies of Boulder, Colorado.

Figures 5 and 7 show a preferred camera bar assembly 30. In this embodiment, camera bar assembly 30 is comprised of two or more electromagnetic sensor heads at opposite (distal) ends of a support bar 36. Support bar 36 illustratively has a rectangular shape and includes a front side 38 which faces vehicle 10. Preferably, support bar 36 has a left aperture 40 and a right aperture 42 formed therein. Linear camera unit 32 resides within aperture 40 and linear camera unit 34 resides within aperture 42. As best illustrated in Figure 9, a plurality of slits or openings 82 and 84 are formed in support bar 36 to provide linear camera units 32 and 34 with a plurality of planar paths

from which to "view" the emitters of wheel targets 12, 14, 16, and 18. Linear camera units 32 and 34 provide to control and display console 60 data signals that correspond to the particular paths in which the wheel target emitters lie. Control and display console 60 calculates the positions of emitters 52a-c, 54a-c, 56a-c, and 58a-c and therefrom calculates alignment parameters and may ascertain the condition of the suspension system, as described below.

In use, camera bar assembly 30 is placed near the front or, optionally, the rear of the vehicle. The positions of the front and rear wheel targets are detected (essentially) simultaneously.

Figure 6 depicts the position of camera bar assembly 30 with respect to wheel targets 12, 14, 16, and 18. Wheel targets 12, 14, 16, and 18 are attached to vehicle wheels 28a - 28d, respectively, by wheel clamps such that right-side target emitters 52a – 52c and 54a – 54c are within the field of view of right camera 34 and left-side target emitters 56a – 56c and 58a – 58c are within the field of view of left camera 32. The camera bar receives signals from the emitters and provides signals to control and display console 60. Control and display console 60 associates each received signal with a particular emitter. Emitter association may be accomplished through any one of a number of techniques, such as time division. Under the control of display and control console 60, each emitter emits a signal at a time that is different from the time a signal is emitted by any other emitter. An example is by controlling the time each emitter emits a signal pulse within a sequence. Sequential generation of electromagnetic radiation pulses enables control and display console 60 to associate a received signal with a particular emitter.

Time division operation is just one way to distinguish emitted pulses from one another; other approaches that rely on pulse duration and/or duty cycle, or emitter signature might be employed. For example, an emitted pulse may be accompanied by or include a digital signature, may provide a unique signal frequency, or have some other distinguishing characteristic that is communicated to control and display console 60 for emitter identification.

Preferably, camera bar 30 is of a sufficient length such that, from a single, stationary camera bar position, right side linear camera unit 34 may view wheel targets 12 and 14 and left side linear camera unit 32 may view wheel targets 16 and 18.

In another embodiment (not shown), camera bar 30 may have only a single electromagnetic sensor head . Consequently, camera bar 30 may be moved alternately to the left and right sides of vehicle 10 so that wheel targets 12 and 14 are viewed from a first camera bar position and wheel targets 16 and 18 are viewed from a second camera bar position. The sensor head is preferably centrally located, but may be positioned at any location along the camera bar. In this embodiment,

a reference emitter is positioned at a single position on or in proximity to vehicle 10. The reference emitter will be viewable from both the first and second camera bar positions and provide a relative reference point from which the first and second camera bar positions may be defined. To facilitate camera bar mobility, the length of the camera bar of this embodiment is preferably shorter than a camera bar having a plurality of sensor heads.

In another embodiment, a camera bar having a single electromagnetic sensor head may view both the left and right sides of vehicle 10 from a single camera bar position. In this embodiment, splitter optics may be employed for providing a first optical path from the sensor head to wheel targets 12 and 14 and a second optical path from the sensor head to wheel targets 16 and 18. In a further aspect of this embodiment, a splitter optic system may include a plurality of reflective surfaces, such as mirrors, located at predetermined positions for reflecting images of wheel targets 12, 14, 16, and 18 to the sensor head. The sensor head may also receive a plurality of signals from emitters located at predetermined positions on each reflective surface. The sensor head may provide to control and display console 60 signals that correspond to the positions of the wheel target and reflective surface emitters. Based upon the signals received from the sensor head, control and display console 60 may be programmed to ascertain the orientation and position of each reflective surface and the position of each wheel target emitter and calculate alignment and suspension parameters therefrom.

Electromagnetic Sensor Head

Camera bar assembly 30 includes an apparatus that provides signals corresponding to or indicative of the relative positions of the electromagnetic radiation emitters within its "field of view."

Camera bar assembly 30 includes at least one electromagnetic sensor head for sensing electromagnetic radiation signals and for providing data signals responsive to the locations of active emitters. An electromagnetic sensor head preferably includes receptors for receiving electromagnetic radiation signals. For example, an electromagnetic sensor head may include an active pixel sensor such as one or more groupings of charge coupled devices (CCDs). In this example, each group of CCDs comprises a receptor, and a selected group of receptors comprises one electromagnetic sensor head. Active pixel sensors may also embody other sensors such as complementary metal-oxide semi-conductors, photodiodes, charge injection devices (CIDs), static gate induction transistors, base-stored image sensors, microbolometers, double-gate floating surface transistors, charge and bulk charge modulation devices, or infrared devices.

In the preferred embodiment, camera bar assembly 30 includes two linear camera units 32 and 34 that comprise two electromagnetic sensor heads. One linear camera unit is located at each end of support bar 36, as illustrated in Figure 7, and includes linear groups of pixels. For example, each linear camera unit may have three linear groups of CCDs. Other linear camera unit configurations may also be provided. For example, camera bar assembly 30 may include three or more linear camera units located at different positions along camera bar 30 or extending the length thereof. Camera bar 30 may include other active pixel sensor groupings, such as two-dimensional area arrays, discussed below.

Referring to Figure 7, the presently preferred embodiment includes three sets of CCDs, 70a-c and 72a-c. As shown in Figure 8, a CCD set consists of a number N of CCDs, or pixels, 74 in a line. As depicted in Figures 8 and 9a and 9b, a thin slot 80 is formed, and in the preferred embodiment this slot is located in support bar 36, in front of and in proximity to each set of CCDs. In this embodiment, the support bar functions as an electromagnetic radiation shield. The CCD pixel and slot configuration allows a limited number of pixels in a CCD set to receive signals from an active emitter. The pixel area receiving the highest intensity of electromagnetic radiation produces the greatest signal through means well known in the art of linear cameras and digital signal processing (DSP). Control and display console 60 receives a signal from optical camera bar assembly 30 corresponding to the linear camera unit, CCD set, and pixel area that received the highest intensity of electromagnetic radiation. Control and display console 60 calculates an angle α, shown in Figure 8, relative to the front side 38 of camera bar assembly 30. Angle α is defined, in part, by the plane that intersects both the emitter and the pixel area receiving the highest intensity of light.

Referring again to Figure 7, in the preferred embodiment of the invention, each linear camera unit has three pixel sets arranged in a "– | –" formation. In this configuration, when an LED or other electromagnetic radiation source lies within the "field of view" of all three pixel sets, such as 70 a, b, and c, control and display console 60 defines three planes that intersect at a point P 52 (see Figure 8), which is the detected location of an emitter.

Linear pixel sets may be arranged in other formations. For example, three pixel sets may be arranged in a triangular formation. A linear camera may include four or more pixel sets arranged in any one of numerous configurations, provided that a detected radiation source lies within the field of view of at least three pixel sets and a single line would not intersect two of the three pixel sets perpendicularly.

Control and display console 60 determines the position of the emitters on each wheel target relative to a reference point. In the preferred embodiment, the reference point is associated with the linear camera. Based upon the relative position of each emitter on a target and upon principles of triangulation, control and display console 60 determines the relative position and orientation of the wheel target. From the relative position and orientation of each wheel target, control and display console 60 determines the positions and alignment parameters of the vehicle wheels, in a manner that is well known in the art of vehicle wheel alignment. Wheel target information may also indicate whether suspension system components are worn, broken, bent, or otherwise damaged. Control and display console 60 may thereby provide an indication of the condition of the suspension system.

Camera bar assembly 30 and control and display console 60 measure the relative angular position or, in an alternative embodiment, Cartesian coordinates, of each emitter of each wheel target. The angular positions are stored in control and display console 60. Control and display console 60 determines the angular position of each wheel target by correlating the angular positions of the emitters of a wheel target with the known geometric configuration the wheel targets. Control and display console 60 determines the angular position of each wheel of a vehicle by correlating the angular position of a wheel target with a determined wheel mount offset angle. The wheel mount offset angle is determined by ascertaining the position of the emitters on a target at two tire rotation positions. Based upon the angular positions of the wheels relative to at least one reference point, control and display console 60 determines the angular positions of the wheels relative to one another, and therefrom determines and displays wheel alignment parameters.

In another embodiment, camera bar assembly 30 includes an area camera, as illustrated in Figure 11. An area camera may be comprised of a two dimensional array of CCDs 90. For example, array 90 may be a 512 x 512 pixel set. A circular aperture 92 may be located in support bar 36 in front of the CCD array. Control and display console 60 may receive a signal from the pixel area 94 receiving the highest intensity of electromagnetic radiation and therefrom define a line 96 intersecting the active emitter. Control and display console 60 may receive a second signal from a second CCD array 98 and define a second line 100 intersecting the active emitter. Control and display console 60 may determine the location of the active emitter by calculating the coordinates of the point where the lines 96 and 100 intersect, as illustrated in Figure 11.

Camera bar assembly may also be comprised of one or more area cameras and one or more linear cameras. The location of an active emitter may be determined from the intersection of three or more planes, two or more lines, or at least one line and one plane.

Determining Alignment Parameters

The camera bar provides to the control and display console 60 data signals that correspond to the detection of electromagnetic signals. In the preferred embodiment, the control and display console receives data signals that correspond to the detection of the electromagnetic signals from at least three wheel target emitters. The signal from each emitter is received by three receptors. As discussed above, the control and display console is preprogrammed with the locations of the three emitters on the wheel target.

In the present embodiment, the data signals provided by the camera bar correspond to two yaw coordinates and one pitch coordinate for an activated emitter. The control and display console transposes all coordinates relative to a fixed point on the camera bar, denoted $(X, Y, Z)_{datum\ zero}$. In the preferred embodiment, datum zero is located at the midpoint of the camera bar. Provided all three emitters on a target have been active, the control and display console obtains the coordinates for each emitter relative to the center of the camera bar.

Because the exact configuration of the wheel target is preprogrammed in the control and display console, the coordinates for the center of the target are easily determined from the coordinates of the active emitters on the target. The coordinates for the center of the target may be expressed relative to the center of the camera bar. The target center coordinates are defined as (X_{TC}, Y_{TC}, Z_{TC}).

As discussed above, each target has a wheel clamp associated therewith for attachment to a vehicle wheel. Although different attachment devices may be utilized for coupling the wheel clamp to the wheel, it is preferable that the wheel clamping device include rim claws for attachment to the wheel rim. A preferred wheel clamping device and associated wheel target is shown in Figure 12. The wheel clamping device includes a plurality of claws 110 for clamping to the rim of a wheel. Preferably, the wheel clamp is adjustable for fitting to a plurality of wheel rim sizes. In this embodiment, the wheel clamp is manually adjustable, through grip 112 for increasing and decreasing the distance between the upper and lower claws 110.

The control and display console is preprogrammed with a geometric model of the wheel clamp and target assembly, including the emitters. Based upon the detected positions of the target emitters and the known distances between points on the clamp-target assembly, the control and display console may determine the midpoint of the surface defined by the points where the wheel clamp claws contact the wheel rim, i.e., the claw datum zero point which corresponds to the center of the wheel rim.

Preferably, the control and display console is preprogrammed to determine the position of the wheel and defines wheel position by the line that is normal to the rim plane and passes through the claw datum zero point, i.e., the Claw Normal Vector. The Claw Normal Vector for position 1 of the wheel may be expressed as:

$$\text{Claw Normal Vector}_1 \equiv (X_1, Y_1, Z_1, \text{Camber}_1, \text{Toe}_1, \text{Roll}_1);$$
$$\text{where } (X_1, Y_1, Z_1) \equiv \text{claw datum zero}_1$$

The Claw Normal Vector is defined relative to the midpoint of the camera bar, i.e., datum zero and is coincident with a line that is normal to the rim plane and passes through claw datum zero. With reference to Figure 13, Camber_1, Toe_1, and Roll_1 for the wheel in position 1 are defined as follows:

Camber_1	$\equiv$	angle representing the inward or outward tilt from true vertical of the wheel
Toe_1	$\equiv$	angle formed by horizontal line within the claw plane and the line that intersects the midpoint between the front wheels and the midpoint between the rear wheels
Roll_1	$\equiv$	for the wheel at position 1, the roll angle may conveniently be defined as 0

With the vehicle in position 1, control and display console preferably defines a Claw Normal Vector for each wheel under inspection.

To ascertain additional wheel alignment parameters, the vehicle is rolled to a second location and a second Claw Normal Vector is calculated for each wheel under inspection. Preferably the second location corresponds to the vehicle rolled back (or forward) 6-8 inches from its first position, which, for most vehicles, corresponds to between 10 and 30 degrees of wheel rotation. The procedure described above for determining and expressing target planes for all of the wheel targets

is repeated with the vehicle at position 2, as illustrated in Figure 14. A Claw Normal Vector for a wheel at position 2 may be expressed as follows:

$$\text{Claw Normal Vector}_2 \equiv (X_2, Y_2, Z_2, \text{Camber}_2, \text{Toe}_2, \text{Roll}_2);$$
$$\text{where } (X_2, Y_2, Z_2) \equiv \text{claw datum zero}_2$$

The camber and toe measurements at position 2 are similar to the angular measurements defined above. The roll measurement at position 2 corresponds to the degree of wheel rotation relative to position 1, as illustrated in Figure 15.

The wheel clamp/target assembly of the present embodiment yeilds a wheel axis of rotation that intersects the target plane at a point that moves only forward and/or rearward as the vehicle is moved forward and/or rearward, i.e., the line of rotation of the target is the line of rotation of the wheel. Control and display console 60 is further programmed for calculating the axis of rotation for each wheel based upon the first and second claw normal vectors:

$$\begin{array}{ll}
\text{Wheel}_1\text{:} & \text{Axis of Rotation}_1(\text{Claw Normal Vector}_{1.1}, \text{Claw Normal Vector}_{1.2}) \\
\text{Wheel}_2\text{:} & \text{Axis of Rotation}_2(\text{Claw Normal Vector}_{2.1}, \text{Claw Normal Vector}_{2.2}) \\
\text{Wheel}_3\text{:} & \text{Axis of Rotation}_3(\text{Claw Normal Vector}_{3.1}, \text{Claw Normal Vector}_{3.2}) \\
* & * \\
* & * \\
* & * \\
\text{Wheel}_N\text{:} & \text{Axis of Rotation}_N(\text{Claw Normal Vector}_{N.1}, \text{Claw Normal Vector}_{N.2})
\end{array}$$

The axis of rotation may be determined by calculating the transform matrix that maps the first claw normal vector to the second claw normal vector. The transform matrix may be determined in the manner described in USP 5,535,522 (Jackson), entitled "Method and Apparatus for Determining the Alignment of Motor Vehicle Wheels," incorporated herein by reference.

The transform matrix calculation is vectorially illustrated in Figures 16(a-c). Figure 16(a) and 16(b) show the claw normal vectors for the wheels in positions 1 and 2, respectively. In Figure 16(c), the claw normal vectors are superimposed so that claw datum zero$_1$ coincides with claw datum zero$_2$ at the point of coincidence.

An arc may be defined between the wheel roll angle measurements at positions 1 and 2 ($Roll_1$ and $Roll_2$), as shown in Figure 15. The angular length of the arc is:

$$ARC_1 \equiv Roll_{1.2} - Roll_{1.1}$$

As illustrated in Figure 17, a cone may be defined by setting the endpoints of ARC_1 between the lines defined by Claw Normal $Vector_1$ and Claw Normal $Vector_2$. The center line of the cone defines the axis of rotation for the wheel (Axis of $Rotation_1$).

Preferably, the control and display console is programmed to determine an axis of rotation for each wheel of the vehicle. The axes of rotation of the wheels may be used to calculate wheel alignment parameters in a manner that is well known in the art.

In the preferred embodiment, the control and display console is preprogrammed for measuring the caster angles of the steerable wheels. To obtain caster angles, a first target plane is measured when the wheels are turned about 10 degrees to the right and a second target plane is measured when the wheels are turned about 10 degrees to the left. For each steerable wheel, an axis of rotation is determined from the first and second target planes, similar to the manner described above. The resultant axis of rotation is the steering axis of rotation for the wheel.

The control and display console may be preprogrammed for measuring parameters that further indicate the condition of the steering linkage, such as SAI (steering angle of inclination), wheel setback, included angles and other vehicle wheel and suspension parameters well known in the art. "Suspension and Steering: ASE Study Guide by Chek-Chart," published by Chek-Chart publications, 1998, incorporated herein by reference, includes a discussion of geometric relationships and measurements pertaining to wheel alignment and vehicle suspension that may be determined in accordance with the present invention.

The control and display console may also be programmed to determine wheel axial stability parameters. To determine axial stability parameters, camber, toe, and roll angle measurements are obtained for each wheel in first, second, and third wheel roll positions. Therefrom, the control and display console may determine wheel runout and axial stability parameters in the manner described in US Patent Application 08/965,032, entitled "Apparatus and Method for Determining Axial Stability," filed November 5, 1997 and assigned to Snap-on Technologies, Inc., and incorporated herein by reference.

Based upon the information received by the camera bar and the axes of rotation of the vehicle wheels, the control and display console may be programmed to compute one or many wheel alignment parameters. For example, front toe may be computed by transposing the axes of rotation of the front two wheels onto a horizontal plane and determining the angular difference between the transposed axes of rotation. Additional wheel alignment parameters may be computed from the axes of rotation of the wheels in a manner that is well known in the art.

Graphical Display Format

The control and display console 60 is preferably equipped with a program for providing alignment measurement data in a graphical format to the display generator. Alignment data is displayed in a format that is readily understandable by automotive service mechanics. Figure 10 shows a preferred display format of wheel alignment parameters, as provided by control and display console 60. The preferred display provides front wheel measurements within the upper half of the screen. Displayed front wheel measurements include caster angle, camber angle, and toe angle. Three columns are provided on the right half of the screen for displaying measurements for the left wheel, the average of both wheels, and the right wheel, respectively. Rear wheel measurements are displayed within the lower half of the screen. Displayed rear wheel measurements include camber angle, toe angle, and thrust angle. Measurements for the left wheel, average, and right wheel are aligned within the three columns described above. In other embodiments, any of the other wheel alignment or suspension parameters discussed above may be displayed on the display screen. Additional display formats may be found in the Operator's Manual for the John Bean Company™ Visualiner Series V8/V9 Wheel Aligner (First Edition, 1998).

Control and display console 60 may also be programmed to display the condition of the suspension system, as ascertained from the active target measurements. Such a display may suggest that a particular component be inspected visually, may suggest that certain other tests be performed, or may indicate on a textual or graphical display whether certain components are good or bad. The suspension system condition and wheel alignment measurements may be displayed separately or on the same screen or printout.

System Operation

The active target wheel aligner of the preferred embodiment operates as follows: Figure 5 represents a top view of a four-wheeled vehicle such as an automobile and shows that camera bar assembly 30 is placed near the body of the automobile. Wheel clamp assemblies 20, 22, 24, and 26 with active wheel targets 12, 14, 16, and 18 are mechanically mounted on the vehicle wheels. Once activated, control and display console 60 causes emitters 52(a-c) to 58(a-c) to pulsate in sequence. Linear camera units 32 and 34 on the camera bar assembly detect the electromagnetic (preferably infrared light) pulses from each emitter and provide control and display console 60 with data corresponding to the intensity of the signal received across the face of each CCD set. Linear camera units 32 and 34 provide CCD data to control and display console 60 for each emitter on the left and right wheel targets, respectively. Control and display console 60 calculates the angular coordinates of the emitters on the right side of the vehicle relative to linear camera unit 34 and calculates the angular coordinates of the emitters on the left side of the vehicle relative to linear camera unit 32. Control and display console 60 then transforms the angular coordinates of the right and left emitter sets to a common coordinate system by relating the known distance between the linear camera units to the right and left angular coordinate sets. The positions and orientations of each active target is determined from the angular coordinates of the emitters. Control and display console 60 then calculates and displays alignment parameters.

The present system may be used to measure all of the traditional alignment parameters mentioned earlier. For example, the positions of the wheels can be measured as the wheels are turned to the left and to the right. From the data obtained, the steering axis of the front-right and front-left of the vehicle can be readily calculated in a manner well known in the art. The present system can also measure both front and rear setback and wheel side-set and eliminates the need to move alignment heads between wheels to measure setback. Also, note that the present invention is operable across a wide range of wheel base dimensions.

The present system can also be used to measure the wheel alignment of vehicles such as trucks and buses with three or more axles. Six, eight or more wheels can be measured using a single camera bar assembly, and adding extra targets for the additional wheels.

Wheel Alignment System In Conjunction With Vehicle Frame Measurement System

The wheel alignment system disclosed herein can be used in conjunction with an electromagnetic radiation vehicle body measurement system, such as the Brewco™ Wolf system,

disclosed in U.S. Patent Application Serial No. 09/029,139, incorporated herein by reference. In this alternative embodiment, in addition to attaching wheel targets to the vehicle wheels, fixed targets of the type used in the Brewco™ Wolf body measurement system may be attached to the vehicle. The fixed targets used in the Wolf system include a plurality of single-point emitters for attachment to or association with the vehicle frame. The Wolf system includes a camera bar assembly and control and display console of the type preferred in the present invention. The Wolf system also includes a data processor that uses triangulation to find the relative locations of the single-point emitters. Accordingly, the display console of the present invention may be programmed to calculate and display vehicle frame parameters as well as wheel alignment parameters.

The apparatus disclosed herein benefits from the accuracy provided by optical wheel alignment systems yet is not as susceptible to damage or require close to optimum operating conditions, as required by prior art wheel aligners. Because the control and display console requires a minimum of only three points to determine the location and orientation of the wheel targets, only single point emitters are required on the wheel targets for detection by a sensor head. Thus, the wheel targets need not include delicate and bulky parts for providing signals to a sensor. Instead, the wheel targets need support only the emitters and, consequently, may be easily manufactured and be more rugged, lightweight, and easier to handle than prior art wheel targets. Because the locations of only single points need be ascertained by the control and display console, the normal conditions of a vehicle repair shop does not adversely affect the performance of the wheel alignment system and wheel targets at relatively long distances from the camera bar are easily detected. The system may be set up relatively easily and quickly and provide individual wheel run-out measurements as soon as a wheel clamp is mounted on a wheel.

The camera bar of the wheel alignment apparatus of the present invention may be configured to view all of the targets on both sides of the vehicle from a single position. Thus, the operator may view the wheel alignment and suspension system parameters, perform adjustments or repairs, and view the resulting parameters on the display.

While the invention has been particularly shown and described with reference to certain preferred embodiments, it will be understood by those skilled in the art that various alterations and modifications in form and in detail may be made therein without departing from the spirit and scope of the invention.

We claim:

1. An apparatus for measuring at least one vehicle wheel position and stability parameter, comprising:

a wheel clamp securable to a wheel of a vehicle;

a plurality of electromagnetic radiation emitters affixed to said wheel clamp in a predetermined spatial configuration;

a sensor for receiving electromagnetic radiation signals from said plurality of electromagnetic radiation emitters and for providing data signals responsive thereto; and

a processor for receiving said data signals and programmed for calculating at least one wheel position and stability parameter based upon said data signals and said predetermined spatial configuration.

2. The apparatus of claim 1 wherein said plurality of electromagnetic radiation emitters comprises three light emitting diodes affixed to said wheel clamp.

3. The apparatus of claim 1 further including:

a plurality of wheel clamps, each having a plurality of electromagnetic radiation emitters affixed thereto in a predetermined spatial configuration, to be secured to respective wheels of the vehicle; and

wherein said processor is programmed for calculating at least one wheel position and stability parameter for at least two wheels of the vehicle.

4. The apparatus of claim 1 wherein said processor is programmed to generate wheel position and stability parameter display signals based upon said data signals and wherein the vehicle wheel position and stability measuring apparatus further comprises:

a display for receiving said wheel position and stability parameter display signals and displaying at least one wheel alignment parameter.

5. The apparatus of claim 1 wherein said processor is programmed to generate wheel position and stability parameter display signals based upon said data signals and wherein the vehicle wheel position and stability measuring apparatus further comprises:

a display for receiving said wheel position and stability parameter display signals and displaying at least one suspension system condition parameter.

6. The apparatus of claim 1 wherein said sensor comprises a linear camera unit.

7. The apparatus of claim 1 wherein said sensor comprises a two-dimensional array camera.

8. The apparatus of claim 6, further comprising a support bar having an aperture formed thereon, and wherein said linear camera unit resides within said aperture.

9. The apparatus of claim 1 wherein said processor is programmed to calculate relative angular coordinates of said emitters based upon the data signals.

10. The apparatus of claim 1 wherein said processor is programmed to determine a claw normal vector of said wheel based upon the data signals.

11. The apparatus of claim 8 wherein said sensor comprises a plurality of linear camera units.

12. The apparatus of claim 1 wherein said wheel clamp comprises a plurality of rim claws at predetermined positions relative to said plurality of electromagnetic radiation emitters and for attachment to a rim of said wheel.

13. An apparatus for measuring the alignment of motor vehicle wheels comprising a wheel alignment camera for receiving electromagnetic radiation signals from electromagnetic radiation emitters associated with the wheels of a vehicle,

said wheel alignment camera comprising:

a plurality of receptors, wherein each said receptor is comprised of a plurality of pixels;

an electromagnetic radiation shield having a plurality of slits formed therein, wherein each said slit is positioned in proximity to at least one said receptor; and

whereby said wheel alignment camera provides output signals in response to receiving electromagnetic radiation signals.

14. The wheel alignment camera of claim 13 wherein said plurality of receptors comprise first, second, and third receptors and wherein said first and second receptors are oriented in a first direction, and said third receptor is oriented in a second, different, direction.

15. The wheel alignment camera of claim 14 wherein said first and second receptors are horizontally oriented and said third receptor is vertically oriented.

16. The apparatus of claim 13 further comprising a programmable computer for receiving output signals from said wheel alignment camera and wherein said computer is programmed to provide data corresponding to wheel alignment and the condition of suspension system components.

17. A wheel alignment target for use in a wheel alignment system for determining the relative position of a wheel, comprising:

a wheel clamp assembly;

a plurality of electromagnetic radiation emitters affixed to one side of said wheel clamp assembly and arranged in a predetermined configuration.

18. The wheel alignment target of claim 17, wherein said plurality of electromagnetic radiation emitters comprises three electromagnetic radiation emitters.

19. The wheel alignment target of claim 17 further comprising a plurality of rim claws at predetermined positions relative to said plurality of electromagnetic radiation emitters and for attachment to a rim of said wheel.

20. An apparatus for measuring vehicle wheel position and stability parameters comprising:

a camera for receiving electromagnetic radiation signals from electromagnetic radiation emitters associated with the wheels of a vehicle,

said camera comprising:

a camera bar having first and second, spaced apart apertures therein; and

first and second sensors associated respectively with said first and second apertures;

wherein, when said camera is positioned to view said electromagnetic radiation emitters, said camera provides signals responsive to said emitters.

21. The camera of claim 20 wherein said first and said second sensors are each comprised of a plurality of sets of charge coupled devices.

22. The camera of claim 20 wherein said first and said second sensors are each comprised of a plurality of sets of active pixel sensors selected from the group consisting of:

(a) complementary metal-oxide semi-conductors
(b) photodiodes
(c) CIDs
(d) static gate induction transistors
(e) base-stored image sensors
(f) microbolometers
(g) double-gate floating surface transistors
(h) charge modulation devices
(i) bulk charge modulation devices; and
(j) infrared devices.

23. An apparatus for measuring vehicle wheel position and stability parameters, comprising:

a plurality of wheel targets attachable to the wheels of a vehicle;

a plurality of emitters affixed to each of said wheel targets;

a camera bar comprising at least one electromagnetic sensor head, removed from said vehicle wheels and in electromagnetic communication with said targets, for sensing the location of said emitters and providing emitter location signals; and

a processing unit for receiving said emitter location signals, calculating vehicle wheel position and stability parameters, and providing display signals.

24. The apparatus of claim 23 wherein each of said wheel targets further comprises a plurality of target legs.

25. The apparatus of claim 24 wherein each of said wheel targets comprises three target legs.

26. The apparatus of claim 23 wherein said wheel targets are attachable to said vehicle wheels via respective single wheel clamp assemblies.

27. The apparatus of claim 23 wherein said target legs extend outward in three directions substantially 120 degrees apart.

28. The apparatus of claim 23 wherein said emitters comprise light emitting diodes.

29. The apparatus of claim 23 wherein said emitters are controlled by said processing unit.

30. The apparatus of claim 23 wherein said emitters are free running and provide a signal to said processing unit for identifying the source of said emitter location signals.

31. The apparatus of claim 23 wherein each said electromagnetic sensor head comprises a linear camera unit comprised of a plurality of charge coupled devices.

32. The apparatus of claim 23 wherein each said electromagnetic sensor head is comprised of a plurality of sets of active pixel sensors selected from the group consisting of:

(a) complementary metal-oxide semi-conductors
(b) photodiodes
(c) CIDs
(d) static gate induction transistors
(e) base-stored image sensors
(f) microbolometers
(g) double-gate floating surface transistors
(h) charge modulation devices
(i) bulk charge modulation devices, and
(j) infrared devices.

33. The apparatus of claim 23 wherein said camera bar is located to the front of said vehicle.

34. The apparatus of claim 23 wherein said processing unit is programmed to determine at least one vehicle wheel position and stability parameter selected from the group consisting of:

(a) wheel camber

(b) wheel caster

(c) thrust line

(d) geometric center line

(e) steering axis

(f) individual toe

(g) wheel offset

(h) wheel setback

(i) SAI

(j) thrust angle

(k) included angles

(l) axial stability; and

(m) wheel runout

35. A method of determining at least one wheel position and stability parameters of a vehicle wheel, comprising the steps of:

associating with said vehicle wheel at least first, second, and third emitters;

determining first locations of said at least first, second, and third emitters, respectively; and

determining a first position and first orientation of said wheel based upon said determined first locations of said at least first, second, and third emitters.

36. The method of claim 34 further comprising the steps of:

determining a plurality of first emitter planes intersecting said first emitter;

determining a plurality of second emitter planes intersecting said second emitter;

determining a plurality of third emitter planes intersecting said third emitter.

37. The method of claim 35 further comprising the steps of:

rolling said vehicle wheel to a second location;

determining second locations of said at least first, second, and third emitters, respectively;

determining a second position and second orientation of said wheel based upon said determined second locations of said at least first, second, and third emitters;

calculating an axis of rotation of said vehicle wheel;

determining at least one wheel alignment parameter based upon said axis of rotation.

38. The method of claim 37 further comprising the step of displaying said at least one wheel alignment parameter.

39. The method of claim 35 further comprising the step of:

activating said first emitter, said second emitter, and said third emitter in sequential order.

40. The method of claim 37 further comprising the steps of:

rolling said vehicle wheel to a third location;

determining third locations of said at least first, second, and third emitters, respectively;

determining a third position and third orientation of said wheel based upon said determined third locations of said at least first, second, and third emitters; and

ascertaining at least one condition of the suspension system of the vehicle based upon said determined first, second, and third positions and orientations of said wheel.

41. The method of claim 40 further comprising the step of determining and displaying the axial stability of the wheel.

42. The method of claim 37 further comprising the steps of:

determining a first claw normal vector for defining said first position and orientation of said vehicle wheel;

determining a second claw normal vector for defining said second position and orientation of said vehicle wheel; and

calculating a transform matrix for mapping said first claw normal vector to said second claw normal vector.

43. The method of claim 40 further comprising the step of determining a third claw normal vector for defining the third position and orientation of said wheel.

44. A method of determining the caster angle of vehicle wheel, comprising the steps of:
associating with said vehicle wheel at least first, second, and third emitters;
turning said wheel to the right;
measuring a first caster angle target plane;
turning said wheel to the left;
measuring a second caster angle target plane;
determining the caster angle of said wheel based upon said first and second caster angle target planes.

45. A method of identifying the relative location of a point on a wheel, comprising the steps of:
attaching an emitter to the wheel;
providing emitter signals;
detecting said emitter signals;
providing emitter position signals based upon said detected emitter signals;
calculating the position of said emitter based upon said emitter position signals.

46. A method for measuring the alignment of the wheels of a motor vehicle, comprising:
positioning a plurality of emitters in a predetermined array on a motor vehicle wheel;
detecting signals generated by said emitters; and
processing detected signals for determining the position and orientation of said wheel and for providing wheel alignment data.

47. The method of claim 46 further comprising the step of emitting pulses of electromagnetic radiation from said plurality of emitters in sequential order.

48. The method of claim 46 wherein said signals generated by said emitters comprise identifiable wavelengths, said method further comprising the step of identifying an emitter based upon the wavelength of an emitted signal.

49. The method of claim 46 further comprising the step of determining first and second claw normal vectors of said wheel while said wheel is at first and second locations, respectively.

Fig. 1

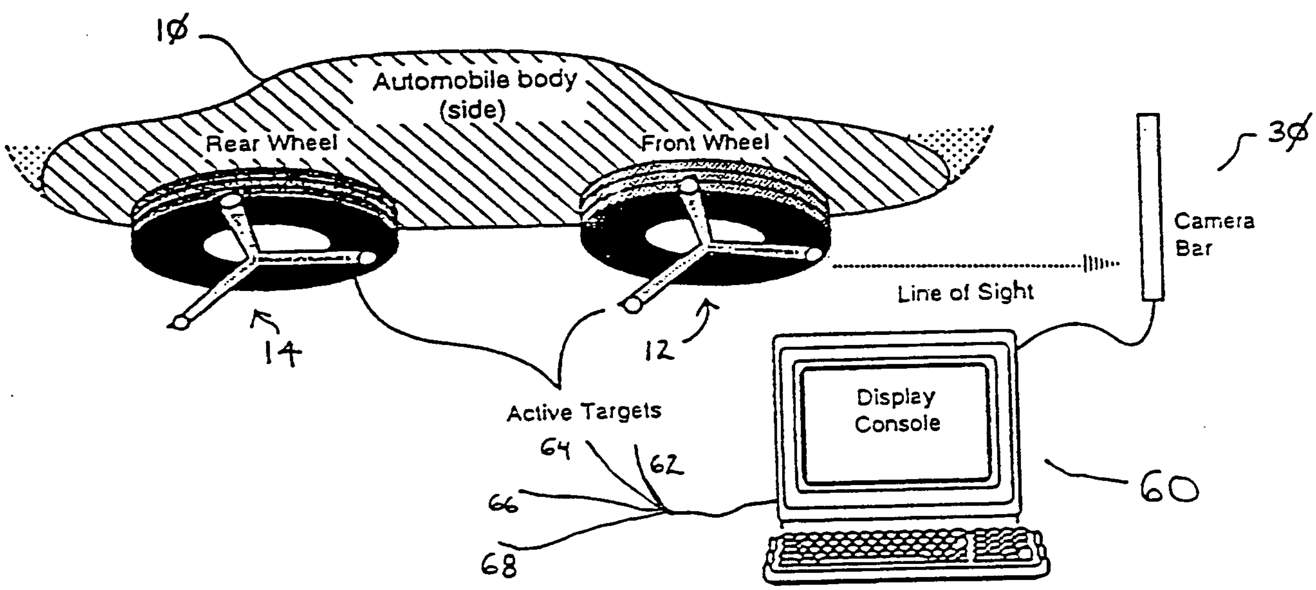

10
Automobile body
(side)
Rear Wheel
Front Wheel
30
Camera
Bar
Line of Sight
14
12
Active Targets
64
62
66
68
Display
Console
60

Fig. 2

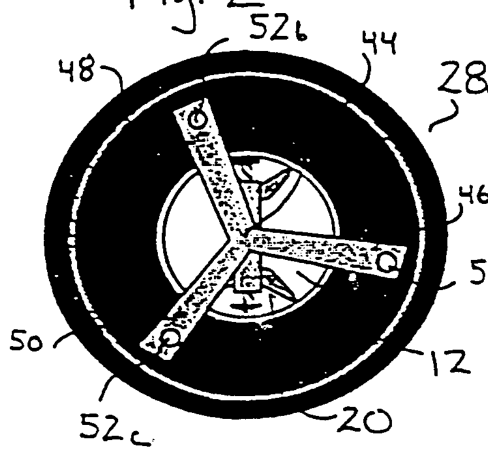


Fig. 4

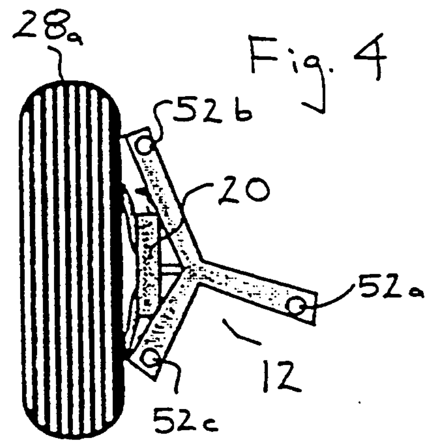


Fig. 3

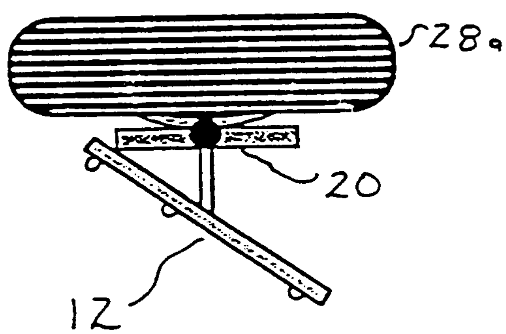


Fig. 5

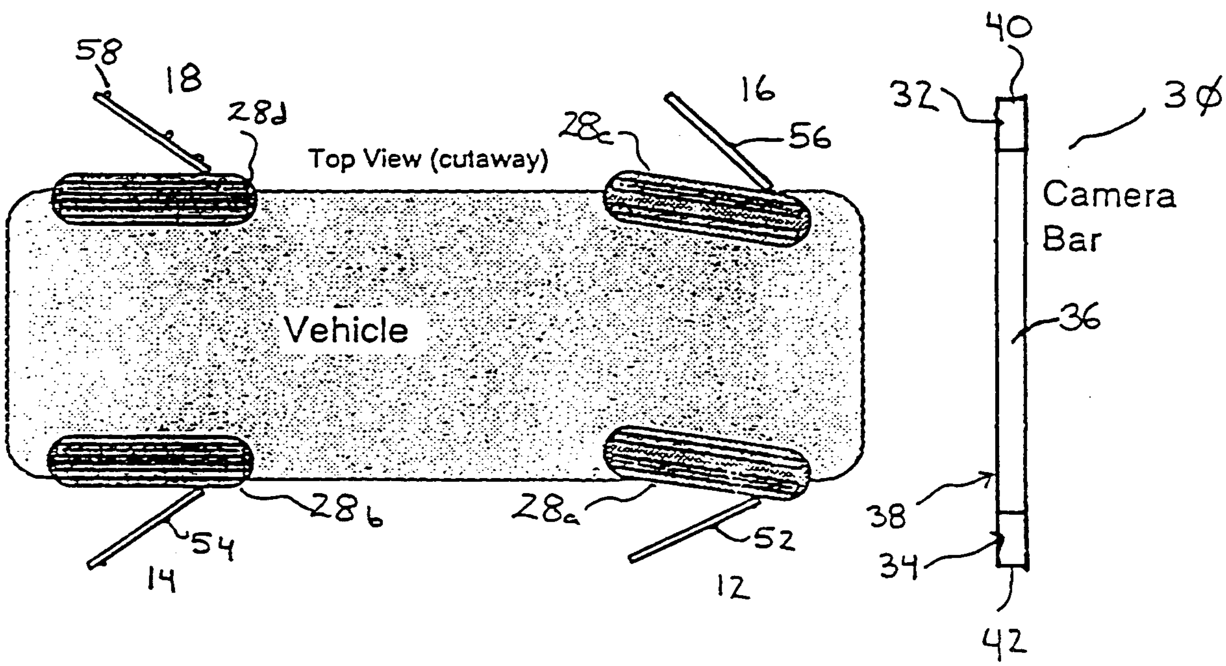
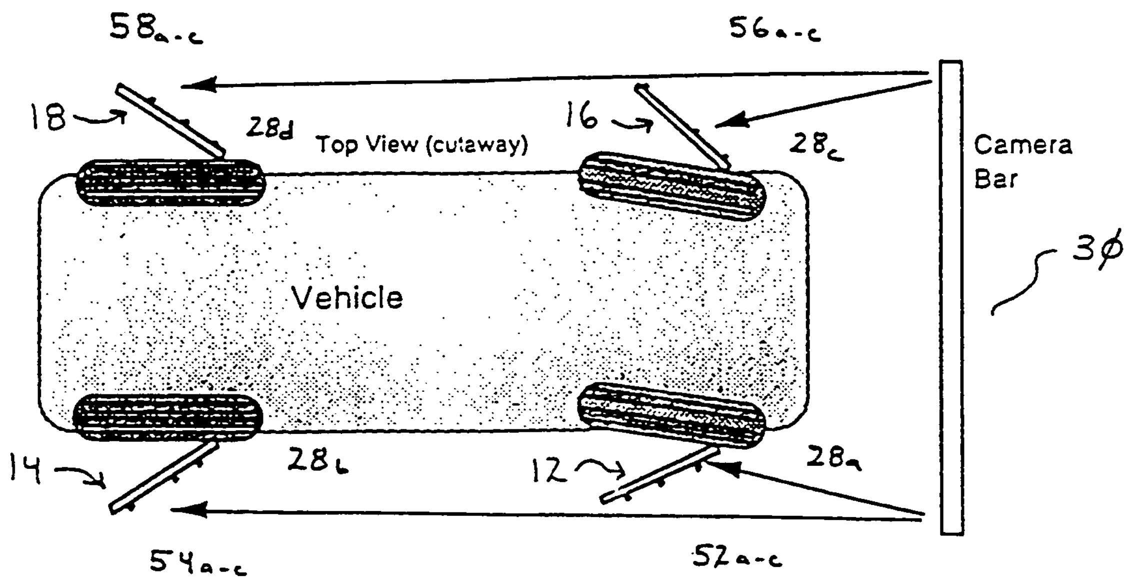

58
18
28d
Top View (cutaway)
16
28c
56
40
32
30
Camera
Bar
Vehicle
36
28b
28a
54
52
38
14
12
34
42

Fig. 6


58a-c
56a-c
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54a-c
52a-c

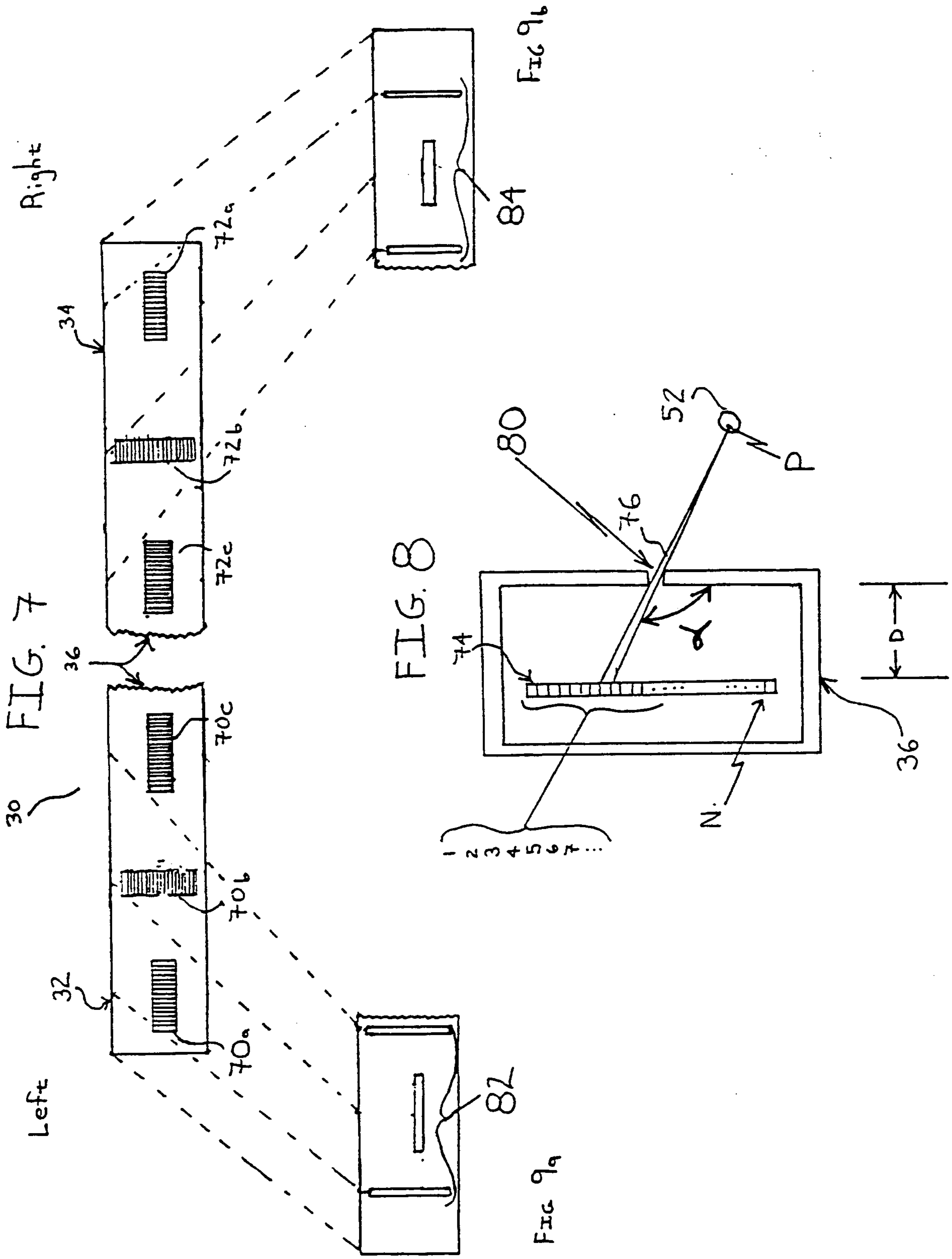


FIG. 7

FIG. 8

FIG 9a

FIG 9b

Fig. 10

Front			
Caster	3.1°		2.7°
Camber	[illegible]1.1°	[illegible]	1.0°
Toe	0.01°	[illegible]	0.09°
Rear			
Camber	-0.4°		0.6°
Toe	0.16°		-0.40°
Thrust Angle		0.3°	
Front Diagnostics			

FIG 11

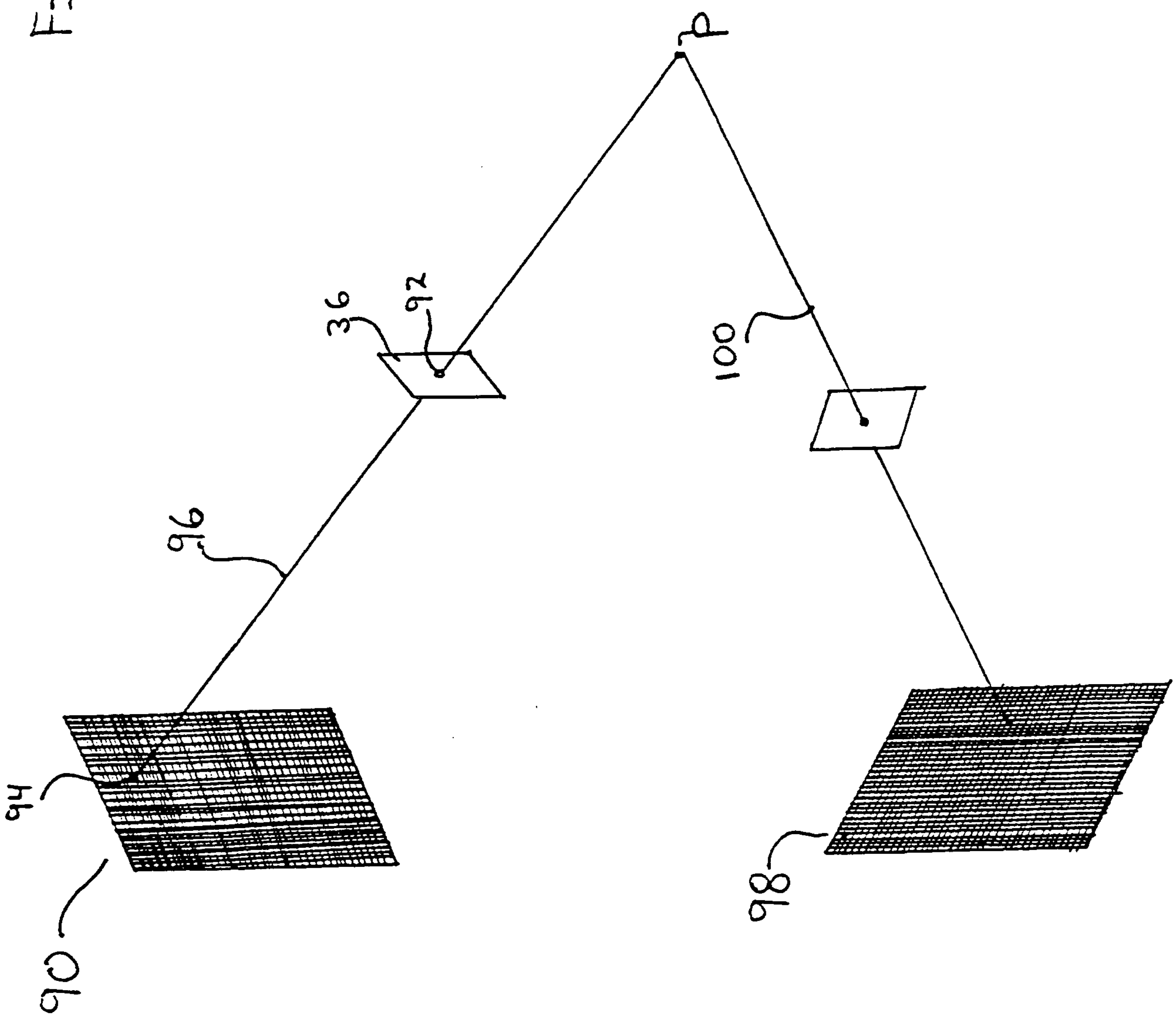


Figure 12

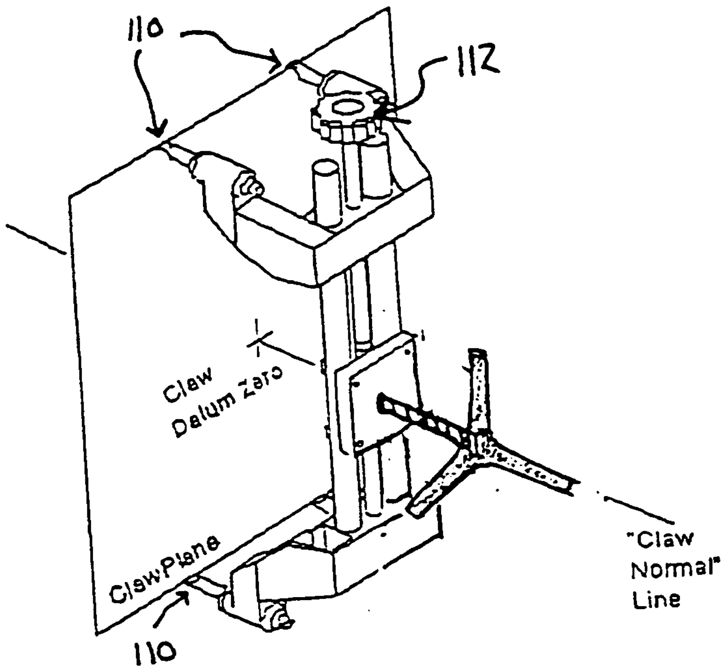


Figure 13

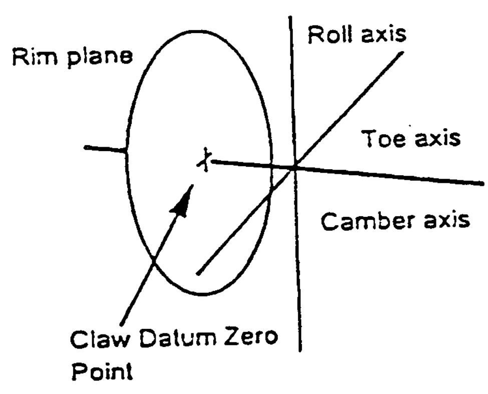


Figure 14

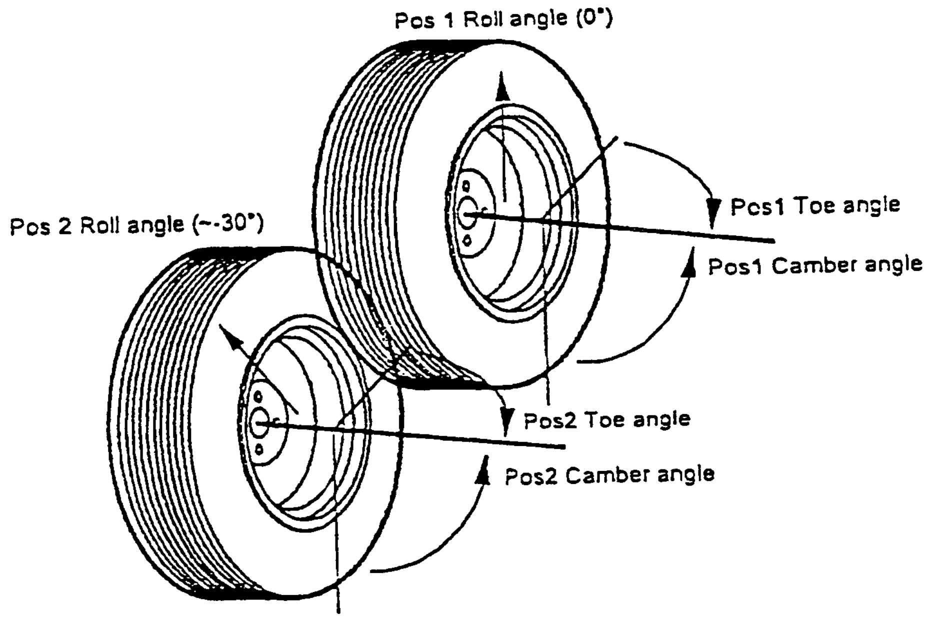


Figure 15

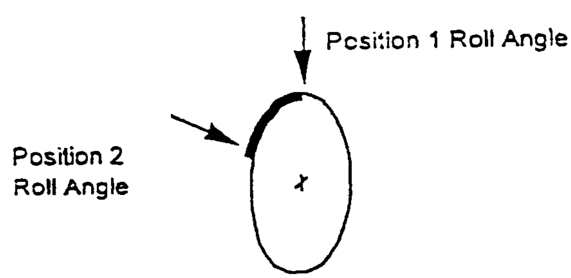


Figure 16

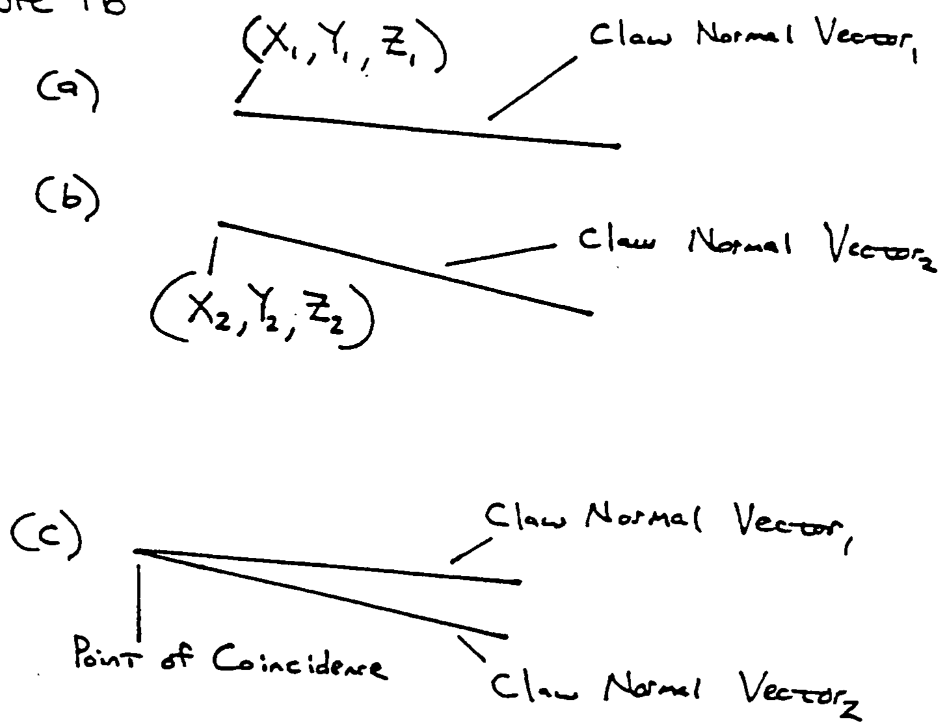
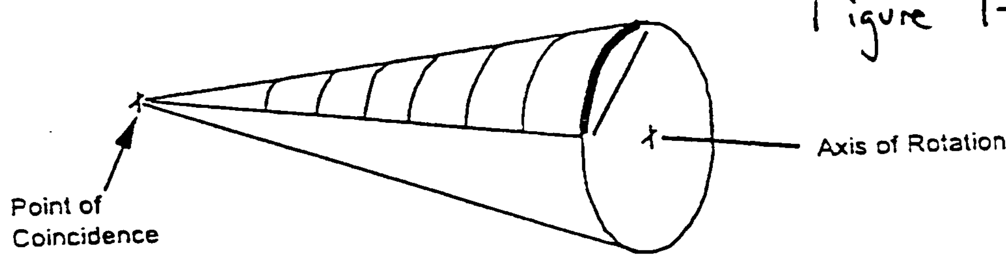


Figure 17



INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/13279

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01B11/275

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 724 743 A (JACKSON BERNIE FERGUS) 10 March 1998 (1998-03-10) cited in the application abstract; figures 1-3,9 column 11 -column 12	1-9,11, 12, 17-19, 23,26, 28,33, 35,44-46
X	US 5 781 286 A (KNESTEL ANTON) 14 July 1998 (1998-07-14) abstract; figures 4-6 column 8 -column 9	13
A		8,20

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 July 2000	01/08/2000

Name and mailing address of the ISA	Authorized officer
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1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/13279

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 675 515 A (JANUARY DANIEL B) 7 October 1997 (1997-10-07) cited in the application abstract; figure 5	44
A	US 4 534 115 A (KASHUBARA DAN) 13 August 1985 (1985-08-13) column 2; figures 1,3,5	1,2
A	EP 0 874 217 A (HOFFMAN WERKSTATT-TECHNIK GMBH) 28 October 1998 (1998-10-28) abstract; figure 1	1

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 00/13279

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5724743 A	10-03-1998	US 5535522 A	16-07-1996
		AU 711728 B	21-10-1999
		AU 7442596 A	30-04-1997
		CA 2232534 A	17-04-1997
		DE 880677 T	06-05-1999
		EP 0880677 A	02-12-1998
		JP 11513789 T	24-11-1999
		WO 9714016 A	17-04-1997
		US 5809658 A	22-09-1998
		US 5969246 A	19-10-1999
		US 5943783 A	31-08-1999
		AU 669211 B	30-05-1996
		AU 4846993 A	29-03-1994
		CA 2143844 A,C	17-03-1994
		EP 0674759 A	04-10-1995
		JP 2936114 B	23-08-1999
		JP 8501155 T	06-02-1996
		WO 9405969 A	17-03-1994
US 5781286 A	14-07-1998	EP 0774646 A	21-05-1997
US 5675515 A	07-10-1997	US 5724128 A	03-03-1998
		AU 3210297 A	09-12-1997
		EP 0840881 A	13-05-1998
		WO 9744635 A	27-11-1997
		US 5870315 A	09-02-1999
US 4534115 A	13-08-1985	NONE	
EP 874217 A	28-10-1998	DE 19717569 A	29-10-1998
		JP 10307003 A	17-11-1998

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 November 2000 (23.11.2000)

PCT

(10) International Publication Number
WO 00/70304 A1

(51) International Patent Classification[7]: G01B 11/275

(21) International Application Number: PCT/US00/13279

(22) International Filing Date: 15 May 2000 (15.05.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/312,788 17 May 1999 (17.05.1999) US

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(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

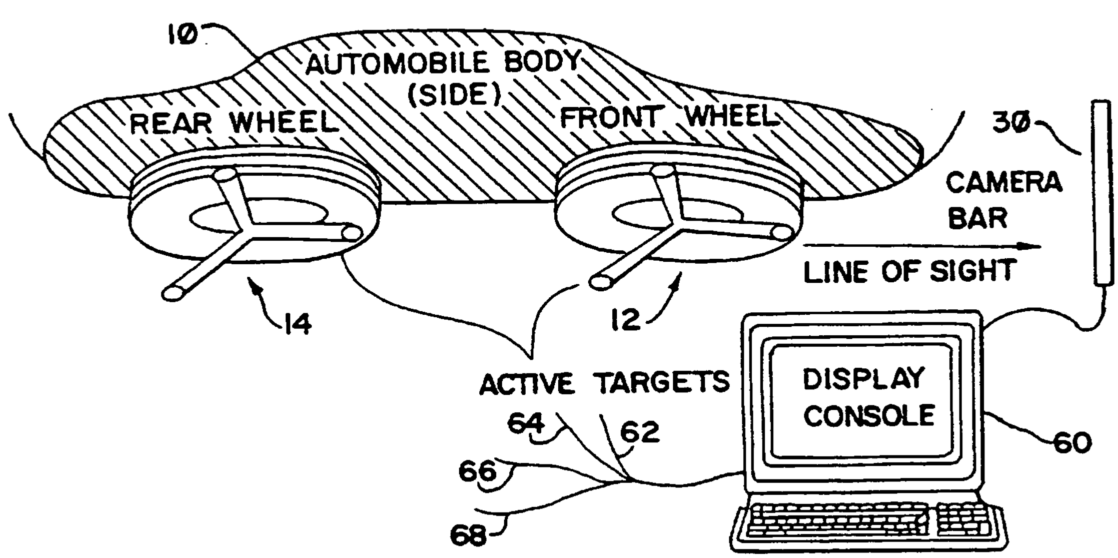
Published:
— *with international search report*

(48) Date of publication of this corrected version:
22 November 2001

(15) Information about Correction:
see PCT Gazette No. 47/2001 of 22 November 2001, Section II

[Continued on next page]

(54) Title: ACTIVE TARGET WHEEL ALIGNER



(57) Abstract: Apparatus and method for determining vehicle wheel alignment parameters and suspension system condition. Wheel targets including electromagnetic radiation emitters emit pulses in timed sequence. A camera boom having an electromagnetic sensor head thereon detects the pulses. A processor receives from the camera head assembly signals that pertain to the relative positions of the emitters. The processor determines the relative angular coordinates of each emitter and therefrom determines the position of the wheel targets. Wheel alignment parameters and/or the condition of the suspension system may be displayed on a display console.

WO 00/70304 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

ACTIVE TARGET WHEEL ALIGNER

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is within the field of wheel aligners. More particularly, this invention is within the arena of optical methods and apparatus for measuring vehicle wheel alignment and detecting suspension system damage.

BRIEF DESCRIPTION OF THE PRIOR ART

Today, as in the past, automotive engineers and car manufacturers are working to meet the demands and standards of the automobile industry. Most standards are established out of environmental, economical, and/or safety considerations. Wheel alignment and vehicle suspension directly affect the efficiency and safety of all motor vehicles, from passenger cars to trucks and busses.

A large number of devices exist for measuring vehicle wheel alignment. Recently, wheel aligners with optical technology have been developed. Examples of wheel aligners that utilize optical technology are disclosed in USPN 5,724,743, USPN 5,535,522, USPN 5,675,515, and USPN 5,657,408. While the optical wheel aligners disclosed in these patents may, in some respects, be easier to utilize than their predecessors, they include delicate and sensitive components that must be handled carefully, often in an environment that is adverse to optical instrumentation. For example, the devices disclosed in both USPN 5,535,522 and 5,675,515 include video cameras that view targets mounted on vehicle wheels. The video cameras provide signals that correspond to images on the targets. The signal-images are processed and analyzed. It is important, therefore, that the wheel targets, and the space between the wheel targets and the camera, remain unadulterated. Whether measuring the wheel alignment of a passenger car, truck, or bus, maintaining such conditions in an automotive repair or wheel alignment shop requires continuous effort. Also, in some instances it is not easy to ascertain whether such conditions are satisfied.

Other prior art optical wheel aligners include delicate and bulky components that require careful manipulation. For example, USPN 5,675,408, discloses an optical wheel alignment system that includes a plurality of laser light sources for attachment to vehicle wheels and rotation therewith.

It is desirable to have a wheel aligner that has the advantages of the prior art optical wheel aligners but does not have the encumbrances discussed above. It is also desirable to provide a device through which the process of measuring wheel alignment may be expedited, e.g., some measurements performed as each wheel clamp is mounted.

Therefore, an advantage of this invention is providing a vehicle wheel alignment apparatus that is rugged and operates well in a coarse environment.

A further advantage of this invention is providing a vehicle wheel alignment apparatus that is lightweight and easy to handle, and has very few delicate components.

Another advantage of this invention is providing a vehicle wheel alignment apparatus that has light and rugged wheel clamp assemblies that are easily and quickly mounted on the wheels of a vehicle.

Yet another advantage of this invention is providing a vehicle wheel alignment method that does not require a complicated or delicate set up procedure and requires minimal effort to maintain in operational condition.

Still another advantage of this invention is providing a vehicle wheel alignment method and apparatus that performs run-out compensation as the wheel clamps are mounted.

A further advantage of this invention is providing a vehicle wheel alignment apparatus that eliminates the need to move the camera head between the wheels to measure setback.

Yet another advantage of this invention is providing a vehicle wheel alignment apparatus that is usable with vehicles such as trucks and buses with three or more axles and is operable across a wide range of wheel base dimensions.

Yet another advantage of this invention is providing a vehicle wheel alignment apparatus that is easy to manufacture and has a minimal number of precision elements to be calibrated.

Yet another advantage of this invention is providing an apparatus and method that ascertains and displays the condition of suspension system components.

SUMMARY OF THE INVENTION

According to various aspects of the invention, an active target wheel aligner preferably includes an electromagnetic radiation sensor for receiving electromagnetic radiation signals from a plurality of electromagnetic radiation emitters associated with a wheel clamp. The active target wheel aligner includes a processor for receiving signals from the sensor and calculating wheel position and

alignment parameters and determining whether the suspension system has worn or damaged components (collectively, wheel position and stability parameters).

In a further aspect of the invention, each emitter is individually activated for a short period of time. An activated emitter produces a pulse of electromagnetic radiation that is easily detected by the sensor. A processor receives a corresponding signal from the sensor and correlates a characteristic of the received signal, such as the time of receipt of the signal, with a particular emitter.

In particular, the apparatus for measuring vehicle wheel alignment of the present invention preferably comprises wheel clamps for providing signals to an electromagnetic radiation sensor head which provides signals to a data processor. Preferably, the wheel clamps are securable to the wheels of a vehicle and have a plurality of electromagnetic radiation emitters affixed thereto in a predetermined spatial configuration. The electromagnetic radiation sensor head receives signals from the plurality of emitters and responsively provides signals corresponding to the relative positions of the emitters. The processor receives the signals and, based upon the predetermined spacial configuration and relative positions of the emitters, calculates wheel alignment parameters and ascertains whether suspension system components are worn or damaged. Preferably, the apparatus of the present invention further comprises a display for displaying wheel alignment parameters and the condition of suspension system components.

The wheel alignment camera preferably includes a plurality of receptors comprised of groups of linearly-adjacent pixel elements for receiving electromagnetic radiation and for providing signals that correspond to electromagnetic radiation intensity. The signals provided by the pixels correspond to the relative positions of the electromagnetic radiation emitters. Preferably, a non-transparent light shield having a plurality of apertures formed therein is positioned in proximity to at least one pixel group and is oriented substantially perpendicular to the group of linearly adjacent pixels.

The preferred emitters emit light in the infra-red spectrum, in a pulsed sequence, so that each emitter operates in sequence at a predetermined time, permitting the receiving apparatus to determine which emitter produced the light that the camera received.

BRIEF DESCRIPTION OF THE DRAWINGS

In describing a preferred embodiment of the present invention, reference is made to accompanying drawings, wherein:

Figure 1 is an illustration of a wheel aligner apparatus in one embodiment of the present invention.

Figure 2 is an illustration of a vehicle wheel and associated wheel clamp and wheel target according to an embodiment of the present invention.

Figure 3 is a plan view of the apparatus of Figure 2.

Figure 4 is a side view of the apparatus of Figure 2.

Figure 5 is a plan representation of an exemplary measurement system implementing the targets shown in Figure 2.

Figure 6 is a plan representation highlighting several aspects of the measurement system of Figure 5.

Figure 7 is an illustration of a camera bar assembly of Figure 5.

Figure 8 is an illustration of part of a linear camera within the camera bar of Figure 7.

Figures 9a and 9b illustrate the camera bar slot arrangements of Figure 7.

Figure 10 is an illustration of a display format provided by the control and display console of the present invention.

Figure 11 is an illustration of a two dimensional active pixel sensor array of another embodiment of the present invention.

Figure 12 is an illustration of a preferred relationship between a wheel and a wheel clamping device and wheel target of one embodiment of the present invention.

Figure 13 is a diagram illustrating a fixed coordinate system for referencing position and attitude of a vehicle wheel in accordance with the present invention.

Figure 14 is a diagram illustrating geometric characteristics of a vehicle wheel as the vehicle is rolled from a first position to a second position in accordance with the preferred embodiment.

Figure 15 is a diagram illustrating the roll angle of the vehicle wheel of Figure 14.

Figures 16(a) through 16(c) are vector diagrams illustrating wheel parameters measured by one embodiment of the present invention.

Figure 17 is a vector diagram illustrating wheel parameters determined by one embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiment of a wheel aligner according to the present invention is illustrated in Figure 1. The apparatus disclosed therein senses the positions of wheel targets and calculates and displays wheel alignment parameters and may also indicate whether components within the suspension system are worn, broken, bent, or damaged.

As shown in Figure 1, targets 12 and 14 are associated with the front and rear wheels, respectively, on the right side of vehicle 10. Preferably, each target is electromagnetically active. A camera bar assembly 30 is positioned in front of vehicle 10. Corresponding front-left active target 16 and rear-left active target 18, not shown, are associated with the wheels on the left side of vehicle 10. Preferably, when camera bar assembly 30 is in its preferred position, active targets 12, 14, 16, and 18 are within its line of "sight". It will be understood that assembly 30 is not ordinarily attached to vehicle 10.

To obtain wheel alignment measurements and/or ascertain the condition of components within the suspension system, one active target is affixed to each vehicle wheel, as described below. An electromagnetic sensor head associated with assembly 30 senses electromagnetic radiation signals from the active targets and provides signals to a control unit. The signals correspond to the location of the active targets.

In the present embodiment, camera bar 30 is situated in front of (or in alternate embodiments, above or behind) vehicle 10, and linear camera units within camera bar assembly 30 provide signals to a control and display console 60. Camera bar assembly 30 may also be situated orthogonally, overhead, or below the vehicle. Control and display console 60 determines the relative position of each active target and its associated wheel. Console 60 includes a data processing unit and a graphic display screen.

Control and display console 60 receives data from camera bar assembly 30 and calculates and displays alignment parameters. The preferred embodiment of the present invention may measure, calculate, and display the camber and caster of a wheel, the thrust line, geometric center line, steering axis, individual toe, offset, setback, steering axis inclination, thrust angle and other parameters well known in the art of vehicle alignment. Additional parameters not mentioned may also be obtained from control and display console 60.

Control and display console 60 may also be programmed to detect symptoms of damaged suspension components such as a bent tie rod or loose ball joint. For example, an excessive toe-in

or toe-out measurement is indicative of a bent tie rod and an unstable or uncertain toe measurement is indicative of a loose ball joint.

The present invention, as described below, may ascertain the condition or reliability of other vehicle components or systems not mentioned above.

Control and Display Console 60

Control and display console 60 preferably includes a data processing unit, such as a programmable computer, and a graphic display screen. In the preferred embodiment of the invention, control and display console 60 includes a personal computer with a keyboard, a printer, and a touch screen display. The computer is programmed to receive data signals from the camera bar and calculate wheel alignment parameters based upon determined positions of the active targets. The computer may provide activation signals to the active targets or may be programmed to correlate some other characteristic of each received signal with a particular emitter.

In an alternative embodiment the processing unit may be comprised of a dedicated processor, memory, and user interface.

Wheel Targets

In keeping with the invention, the wheel targets include a plurality of single-point electromagnetic radiation sources arranged in a predetermined configuration.

As shown in Figures 2-4, in the preferred embodiment, each wheel target is attached to a vehicle wheel by means of a single wheel clamp assembly 20. As best seen in Figure 2, a wheel target 12 may consist of a plurality of target legs extending outward from target center 44. In the preferred embodiment, a wheel target includes three target legs 46, 48, and 50 extending outward in three directions 120° apart. Other wheel target configurations may also be used. For example, the target legs may be of different lengths or may be curved instead of straight. A wheel target may also be comprised of a single target leg or may be generally disk shaped.

A plurality of electromagnetic emitters are associated with each wheel target for providing electromagnetic radiation signals. Three or more emitters may be associated with each wheel target. In the presently-preferred embodiment, one emitter 52 is affixed to the outer end of each target leg, for a total of three emitters per wheel target. The target emitters may be light emitting diodes (LEDs) or any other component capable of emitting a pulsed or modulated or otherwise identifiable electromagnetic radiation signal (hereinafter "light signal"). In the presently-preferred embodiment,

emitters 52a-c are infrared LEDs embedded within the target legs so as not to protrude and be susceptible to damage. In this embodiment, emitters 52 are powered and controlled by control and display console 60 via power cords 62, 64, 66, and 68 (Figure 1). The emitters are pulsed consecutively under control of the control and display console 60. Other techniques may be substituted to correlate received signals with the emitters that produced them. For example, the emitters may be uniquely identified through the use of, for each emitter, a distinct wavelength of light, a distinct modulation frequency, or an emitter signature signal. As explained more fully below, the data processing unit within control and display console 60 is programmed to correlate signals received from camera bar assembly 60 with the particular emitters from which the signals came.

In another embodiment, the emitters are powered by batteries that may be encased within or attached to the wheel targets or wheel clamps. In this embodiment, the emitters are free running and are not connected to control and display console 60 via power cords 62, 64, 66, and 68. The emitter/battery assembly of this embodiment may further include a switch that may be manually activated or activated by control and display console 60 via an electromagnetic (such as infrared radiation), sonic, or other type of signal.

Camera Bar 30

Preferably, a durable and transportable camera bar assembly is provided for receiving pulsed or modulated electromagnetic radiation signals from any one or several of the wheel targets and for providing output signals in response thereto. In the preferred embodiment, the camera bar assembly 30 is similar to the camera of the Wolf measurement system, manufactured by Brewco™ of Central City, Kentucky. The Wolf measurement system is disclosed in U.S. Patent Application Serial No. 09/029,139, entitled "Measuring Device Primarily for Use with Vehicles," filed March 9, 1998 and is incorporated herein by reference. The camera bar is preferably a Flashpoint™ sensor, manufactured by Image Guided Technologies of Boulder, Colorado.

Figures 5 and 7 show a preferred camera bar assembly 30. In this embodiment, camera bar assembly 30 is comprised of two or more electromagnetic sensor heads at opposite (distal) ends of a support bar 36. Support bar 36 illustratively has a rectangular shape and includes a front side 38 which faces vehicle 10. Preferably, support bar 36 has a left aperture 40 and a right aperture 42 formed therein. Linear camera unit 32 resides within aperture 40 and linear camera unit 34 resides within aperture 42. As best illustrated in Figure 9, a plurality of slits or openings 82 and 84 are formed in support bar 36 to provide linear camera units 32 and 34 with a plurality of planar paths

from which to "view" the emitters of wheel targets 12, 14, 16, and 18. Linear camera units 32 and 34 provide to control and display console 60 data signals that correspond to the particular paths in which the wheel target emitters lie. Control and display console 60 calculates the positions of emitters 52a-c, 54a-c, 56a-c, and 58a-c and therefrom calculates alignment parameters and may ascertain the condition of the suspension system, as described below.

In use, camera bar assembly 30 is placed near the front or, optionally, the rear of the vehicle. The positions of the front and rear wheel targets are detected (essentially) simultaneously.

Figure 6 depicts the position of camera bar assembly 30 with respect to wheel targets 12, 14, 16, and 18. Wheel targets 12, 14, 16, and 18 are attached to vehicle wheels 28a - 28d, respectively, by wheel clamps such that right-side target emitters 52a – 52c and 54a – 54c are within the field of view of right camera 34 and left-side target emitters 56a – 56c and 58a – 58c are within the field of view of left camera 32. The camera bar receives signals from the emitters and provides signals to control and display console 60. Control and display console 60 associates each received signal with a particular emitter. Emitter association may be accomplished through any one of a number of techniques, such as time division. Under the control of display and control console 60, each emitter emits a signal at a time that is different from the time a signal is emitted by any other emitter. An example is by controlling the time each emitter emits a signal pulse within a sequence. Sequential generation of electromagnetic radiation pulses enables control and display console 60 to associate a received signal with a particular emitter.

Time division operation is just one way to distinguish emitted pulses from one another; other approaches that rely on pulse duration and/or duty cycle, or emitter signature might be employed. For example, an emitted pulse may be accompanied by or include a digital signature, may provide a unique signal frequency, or have some other distinguishing characteristic that is communicated to control and display console 60 for emitter identification.

Preferably, camera bar 30 is of a sufficient length such that, from a single, stationary camera bar position, right side linear camera unit 34 may view wheel targets 12 and 14 and left side linear camera unit 32 may view wheel targets 16 and 18.

In another embodiment (not shown), camera bar 30 may have only a single electromagnetic sensor head . Consequently, camera bar 30 may be moved alternately to the left and right sides of vehicle 10 so that wheel targets 12 and 14 are viewed from a first camera bar position and wheel targets 16 and 18 are viewed from a second camera bar position. The sensor head is preferably centrally located, but may be positioned at any location along the camera bar. In this embodiment,

a reference emitter is positioned at a single position on or in proximity to vehicle 10. The reference emitter will be viewable from both the first and second camera bar positions and provide a relative reference point from which the first and second camera bar positions may be defined. To facilitate camera bar mobility, the length of the camera bar of this embodiment is preferably shorter than a camera bar having a plurality of sensor heads.

In another embodiment, a camera bar having a single electromagnetic sensor head may view both the left and right sides of vehicle 10 from a single camera bar position. In this embodiment, splitter optics may be employed for providing a first optical path from the sensor head to wheel targets 12 and 14 and a second optical path from the sensor head to wheel targets 16 and 18. In a further aspect of this embodiment, a splitter optic system may include a plurality of reflective surfaces, such as mirrors, located at predetermined positions for reflecting images of wheel targets 12, 14, 16, and 18 to the sensor head. The sensor head may also receive a plurality of signals from emitters located at predetermined positions on each reflective surface. The sensor head may provide to control and display console 60 signals that correspond to the positions of the wheel target and reflective surface emitters. Based upon the signals received from the sensor head, control and display console 60 may be programmed to ascertain the orientation and position of each reflective surface and the position of each wheel target emitter and calculate alignment and suspension parameters therefrom.

Electromagnetic Sensor Head

Camera bar assembly 30 includes an apparatus that provides signals corresponding to or indicative of the relative positions of the electromagnetic radiation emitters within its "field of view."

Camera bar assembly 30 includes at least one electromagnetic sensor head for sensing electromagnetic radiation signals and for providing data signals responsive to the locations of active emitters. An electromagnetic sensor head preferably includes receptors for receiving electromagnetic radiation signals. For example, an electromagnetic sensor head may include an active pixel sensor such as one or more groupings of charge coupled devices (CCDs). In this example, each group of CCDs comprises a receptor, and a selected group of receptors comprises one electromagnetic sensor head. Active pixel sensors may also embody other sensors such as complementary metal-oxide semiconductors, photodiodes, charge injection devices (CIDs), static gate induction transistors, base-stored image sensors, microbolometers, double-gate floating surface transistors, charge and bulk charge modulation devices, or infrared devices.

In the preferred embodiment, camera bar assembly 30 includes two linear camera units 32 and 34 that comprise two electromagnetic sensor heads. One linear camera unit is located at each end of support bar 36, as illustrated in Figure 7, and includes linear groups of pixels. For example, each linear camera unit may have three linear groups of CCDs. Other linear camera unit configurations may also be provided. For example, camera bar assembly 30 may include three or more linear camera units located at different positions along camera bar 30 or extending the length thereof. Camera bar 30 may include other active pixel sensor groupings, such as two-dimensional area arrays, discussed below.

Referring to Figure 7, the presently preferred embodiment includes three sets of CCDs, 70a-c and 72a-c. As shown in Figure 8, a CCD set consists of a number N of CCDs, or pixels, 74 in a line. As depicted in Figures 8 and 9a and 9b, a thin slot 80 is formed, and in the preferred embodiment this slot is located in support bar 36, in front of and in proximity to each set of CCDs. In this embodiment, the support bar functions as an electromagnetic radiation shield. The CCD pixel and slot configuration allows a limited number of pixels in a CCD set to receive signals from an active emitter. The pixel area receiving the highest intensity of electromagnetic radiation produces the greatest signal through means well known in the art of linear cameras and digital signal processing (DSP). Control and display console 60 receives a signal from optical camera bar assembly 30 corresponding to the linear camera unit, CCD set, and pixel area that received the highest intensity of electromagnetic radiation. Control and display console 60 calculates an angle α, shown in Figure 8, relative to the front side 38 of camera bar assembly 30. Angle α is defined, in part, by the plane that intersects both the emitter and the pixel area receiving the highest intensity of light.

Referring again to Figure 7, in the preferred embodiment of the invention, each linear camera unit has three pixel sets arranged in a "– | –" formation. In this configuration, when an LED or other electromagnetic radiation source lies within the "field of view" of all three pixel sets, such as 70 a, b, and c, control and display console 60 defines three planes that intersect at a point P 52 (see Figure 8), which is the detected location of an emitter.

Linear pixel sets may be arranged in other formations. For example, three pixel sets may be arranged in a triangular formation. A linear camera may include four or more pixel sets arranged in any one of numerous configurations, provided that a detected radiation source lies within the field of view of at least three pixel sets and a single line would not intersect two of the three pixel sets perpendicularly.

Control and display console 60 determines the position of the emitters on each wheel target relative to a reference point. In the preferred embodiment, the reference point is associated with the linear camera. Based upon the relative position of each emitter on a target and upon principles of triangulation, control and display console 60 determines the relative position and orientation of the wheel target. From the relative position and orientation of each wheel target, control and display console 60 determines the positions and alignment parameters of the vehicle wheels, in a manner that is well known in the art of vehicle wheel alignment. Wheel target information may also indicate whether suspension system components are worn, broken, bent, or otherwise damaged. Control and display console 60 may thereby provide an indication of the condition of the suspension system.

Camera bar assembly 30 and control and display console 60 measure the relative angular position or, in an alternative embodiment, Cartesian coordinates, of each emitter of each wheel target. The angular positions are stored in control and display console 60. Control and display console 60 determines the angular position of each wheel target by correlating the angular positions of the emitters of a wheel target with the known geometric configuration the wheel targets. Control and display console 60 determines the angular position of each wheel of a vehicle by correlating the angular position of a wheel target with a determined wheel mount offset angle. The wheel mount offset angle is determined by ascertaining the position of the emitters on a target at two tire rotation positions. Based upon the angular positions of the wheels relative to at least one reference point, control and display console 60 determines the angular positions of the wheels relative to one another, and therefrom determines and displays wheel alignment parameters.

In another embodiment, camera bar assembly 30 includes an area camera, as illustrated in Figure 11. An area camera may be comprised of a two dimensional array of CCDs 90. For example, array 90 may be a 512 x 512 pixel set. A circular aperture 92 may be located in support bar 36 in front of the CCD array. Control and display console 60 may receive a signal from the pixel area 94 receiving the highest intensity of electromagnetic radiation and therefrom define a line 96 intersecting the active emitter. Control and display console 60 may receive a second signal from a second CCD array 98 and define a second line 100 intersecting the active emitter. Control and display console 60 may determine the location of the active emitter by calculating the coordinates of the point where the lines 96 and 100 intersect, as illustrated in Figure 11.

Camera bar assembly may also be comprised of one or more area cameras and one or more linear cameras. The location of an active emitter may be determined from the intersection of three or more planes, two or more lines, or at least one line and one plane.

Determining Alignment Parameters

The camera bar provides to the control and display console 60 data signals that correspond to the detection of electromagnetic signals. In the preferred embodiment, the control and display console receives data signals that correspond to the detection of the electromagnetic signals from at least three wheel target emitters. The signal from each emitter is received by three receptors. As discussed above, the control and display console is preprogrammed with the locations of the three emitters on the wheel target.

In the present embodiment, the data signals provided by the camera bar correspond to two yaw coordinates and one pitch coordinate for an activated emitter. The control and display console transposes all coordinates relative to a fixed point on the camera bar, denoted $(X, Y, Z)_{\text{datum zero}}$. In the preferred embodiment, datum zero is located at the midpoint of the camera bar. Provided all three emitters on a target have been active, the control and display console obtains the coordinates for each emitter relative to the center of the camera bar.

Because the exact configuration of the wheel target is preprogrammed in the control and display console, the coordinates for the center of the target are easily determined from the coordinates of the active emitters on the target. The coordinates for the center of the target may be expressed relative to the center of the camera bar. The target center coordinates are defined as (X_{TC}, Y_{TC}, Z_{TC}).

As discussed above, each target has a wheel clamp associated therewith for attachment to a vehicle wheel. Although different attachment devices may be utilized for coupling the wheel clamp to the wheel, it is preferable that the wheel clamping device include rim claws for attachment to the wheel rim. A preferred wheel clamping device and associated wheel target is shown in Figure 12. The wheel clamping device includes a plurality of claws 110 for clamping to the rim of a wheel. Preferably, the wheel clamp is adjustable for fitting to a plurality of wheel rim sizes. In this embodiment, the wheel clamp is manually adjustable, through grip 112 for increasing and decreasing the distance between the upper and lower claws 110.

The control and display console is preprogrammed with a geometric model of the wheel clamp and target assembly, including the emitters. Based upon the detected positions of the target emitters and the known distances between points on the clamp-target assembly, the control and display console may determine the midpoint of the surface defined by the points where the wheel clamp claws contact the wheel rim, i.e., the claw datum zero point which corresponds to the center of the wheel rim.

Preferably, the control and display console is preprogrammed to determine the position of the wheel and defines wheel position by the line that is normal to the rim plane and passes through the claw datum zero point, i.e., the Claw Normal Vector. The Claw Normal Vector for position 1 of the wheel may be expressed as:

$$\text{Claw Normal Vector}_1 \equiv (X_1, Y_1, Z_1, \text{Camber}_1, \text{Toe}_1, \text{Roll}_1);$$
$$\text{where } (X_1, Y_1, Z_1) \equiv \text{claw datum zero}_1$$

The Claw Normal Vector is defined relative to the midpoint of the camera bar, i.e., datum zero and is coincident with a line that is normal to the rim plane and passes through claw datum zero. With reference to Figure 13, Camber_1, Toe_1, and Roll_1 for the wheel in position 1 are defined as follows:

Camber_1	$\equiv$	angle representing the inward or outward tilt from true vertical of the wheel
Toe_1	$\equiv$	angle formed by horizontal line within the claw plane and the line that intersects the midpoint between the front wheels and the midpoint between the rear wheels
Roll_1	$\equiv$	for the wheel at position 1, the roll angle may conveniently be defined as 0

With the vehicle in position 1, control and display console preferably defines a Claw Normal Vector for each wheel under inspection.

To ascertain additional wheel alignment parameters, the vehicle is rolled to a second location and a second Claw Normal Vector is calculated for each wheel under inspection. Preferably the second location corresponds to the vehicle rolled back (or forward) 6-8 inches from its first position, which, for most vehicles, corresponds to between 10 and 30 degrees of wheel rotation. The procedure described above for determining and expressing target planes for all of the wheel targets

is repeated with the vehicle at position 2, as illustrated in Figure 14. A Claw Normal Vector for a wheel at position 2 may be expressed as follows:

$$\text{Claw Normal Vector}_2 \equiv (X_2, Y_2, Z_2, \text{Camber}_2, \text{Toe}_2, \text{Roll}_2);$$
$$\text{where } (X_2, Y_2, Z_2) \equiv \text{claw datum zero}_2$$

The camber and toe measurements at position 2 are similar to the angular measurements defined above. The roll measurement at position 2 corresponds to the degree of wheel rotation relative to position 1, as illustrated in Figure 15.

The wheel clamp/target assembly of the present embodiment yeilds a wheel axis of rotation that intersects the target plane at a point that moves only forward and/or rearward as the vehicle is moved forward and/or rearward, i.e., the line of rotation of the target is the line of rotation of the wheel. Control and display console 60 is further programmed for calculating the axis of rotation for each wheel based upon the first and second claw normal vectors:

$$\text{Wheel}_1\text{:} \quad \text{Axis of Rotation}_1(\text{Claw Normal Vector}_{1.1}, \text{Claw Normal Vector}_{1.2})$$
$$\text{Wheel}_2\text{:} \quad \text{Axis of Rotation}_2(\text{Claw Normal Vector}_{2.1}, \text{Claw Normal Vector}_{2.2})$$
$$\text{Wheel}_3\text{:} \quad \text{Axis of Rotation}_3(\text{Claw Normal Vector}_{3.1}, \text{Claw Normal Vector}_{3.2})$$

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$$\text{Wheel}_N\text{:} \quad \text{Axis of Rotation}_N(\text{Claw Normal Vector}_{N.1}, \text{Claw Normal Vector}_{N.2})$$

The axis of rotation may be determined by calculating the transform matrix that maps the first claw normal vector to the second claw normal vector. The transform matrix may be determined in the manner described in USP 5,535,522 (Jackson), entitled "Method and Apparatus for Determining the Alignment of Motor Vehicle Wheels," incorporated herein by reference.

The transform matrix calculation is vectorially illustrated in Figures 16(a-c). Figure 16(a) and 16(b) show the claw normal vectors for the wheels in positions 1 and 2, respectively. In Figure 16(c), the claw normal vectors are superimposed so that claw datum zero_1 coincides with claw datum zero_2 at the point of coincidence.

An arc may be defined between the wheel roll angle measurements at positions 1 and 2 ($Roll_1$ and $Roll_2$), as shown in Figure 15. The angular length of the arc is:

$$ARC_1 \equiv Roll_{1.2} - Roll_{1.1}$$

As illustrated in Figure 17, a cone may be defined by setting the endpoints of ARC_1 between the lines defined by Claw Normal $Vector_1$ and Claw Normal $Vector_2$. The center line of the cone defines the axis of rotation for the wheel (Axis of $Rotation_1$).

Preferably, the control and display console is programmed to determine an axis of rotation for each wheel of the vehicle. The axes of rotation of the wheels may be used to calculate wheel alignment parameters in a manner that is well known in the art.

In the preferred embodiment, the control and display console is preprogrammed for measuring the caster angles of the steerable wheels. To obtain caster angles, a first target plane is measured when the wheels are turned about 10 degrees to the right and a second target plane is measured when the wheels are turned about 10 degrees to the left. For each steerable wheel, an axis of rotation is determined from the first and second target planes, similar to the manner described above. The resultant axis of rotation is the steering axis of rotation for the wheel.

The control and display console may be preprogrammed for measuring parameters that further indicate the condition of the steering linkage, such as SAI (steering angle of inclination), wheel setback, included angles and other vehicle wheel and suspension parameters well known in the art. "Suspension and Steering: ASE Study Guide by Chek-Chart," published by Chek-Chart publications, 1998, incorporated herein by reference, includes a discussion of geometric relationships and measurements pertaining to wheel alignment and vehicle suspension that may be determined in accordance with the present invention.

The control and display console may also be programmed to determine wheel axial stability parameters. To determine axial stability parameters, camber, toe, and roll angle measurements are obtained for each wheel in first, second, and third wheel roll positions. Therefrom, the control and display console may determine wheel runout and axial stability parameters in the manner described in US Patent Application 08/965,032, entitled "Apparatus and Method for Determining Axial Stability," filed November 5, 1997 and assigned to Snap-on Technologies, Inc., and incorporated herein by reference.

Based upon the information received by the camera bar and the axes of rotation of the vehicle wheels, the control and display console may be programmed to compute one or many wheel alignment parameters. For example, front toe may be computed by transposing the axes of rotation of the front two wheels onto a horizontal plane and determining the angular difference between the transposed axes of rotation. Additional wheel alignment parameters may be computed from the axes of rotation of the wheels in a manner that is well known in the art.

Graphical Display Format

The control and display console 60 is preferably equipped with a program for providing alignment measurement data in a graphical format to the display generator. Alignment data is displayed in a format that is readily understandable by automotive service mechanics. Figure 10 shows a preferred display format of wheel alignment parameters, as provided by control and display console 60. The preferred display provides front wheel measurements within the upper half of the screen. Displayed front wheel measurements include caster angle, camber angle, and toe angle. Three columns are provided on the right half of the screen for displaying measurements for the left wheel, the average of both wheels, and the right wheel, respectively. Rear wheel measurements are displayed within the lower half of the screen. Displayed rear wheel measurements include camber angle, toe angle, and thrust angle. Measurements for the left wheel, average, and right wheel are aligned within the three columns described above. In other embodiments, any of the other wheel alignment or suspension parameters discussed above may be displayed on the display screen. Additional display formats may be found in the Operator's Manual for the John Bean Company™ Visualiner Series V8/V9 Wheel Aligner (First Edition, 1998).

Control and display console 60 may also be programmed to display the condition of the suspension system, as ascertained from the active target measurements. Such a display may suggest that a particular component be inspected visually, may suggest that certain other tests be performed, or may indicate on a textual or graphical display whether certain components are good or bad. The suspension system condition and wheel alignment measurements may be displayed separately or on the same screen or printout.

System Operation

The active target wheel aligner of the preferred embodiment operates as follows: Figure 5 represents a top view of a four-wheeled vehicle such as an automobile and shows that camera bar assembly 30 is placed near the body of the automobile. Wheel clamp assemblies 20, 22, 24, and 26 with active wheel targets 12, 14, 16, and 18 are mechanically mounted on the vehicle wheels. Once activated, control and display console 60 causes emitters 52(a-c) to 58(a-c) to pulsate in sequence. Linear camera units 32 and 34 on the camera bar assembly detect the electromagnetic (preferably infrared light) pulses from each emitter and provide control and display console 60 with data corresponding to the intensity of the signal received across the face of each CCD set. Linear camera units 32 and 34 provide CCD data to control and display console 60 for each emitter on the left and right wheel targets, respectively. Control and display console 60 calculates the angular coordinates of the emitters on the right side of the vehicle relative to linear camera unit 34 and calculates the angular coordinates of the emitters on the left side of the vehicle relative to linear camera unit 32. Control and display console 60 then transforms the angular coordinates of the right and left emitter sets to a common coordinate system by relating the known distance between the linear camera units to the right and left angular coordinate sets. The positions and orientations of each active target is determined from the angular coordinates of the emitters. Control and display console 60 then calculates and displays alignment parameters.

The present system may be used to measure all of the traditional alignment parameters mentioned earlier. For example, the positions of the wheels can be measured as the wheels are turned to the left and to the right. From the data obtained, the steering axis of the front-right and front-left of the vehicle can be readily calculated in a manner well known in the art. The present system can also measure both front and rear setback and wheel side-set and eliminates the need to move alignment heads between wheels to measure setback. Also, note that the present invention is operable across a wide range of wheel base dimensions.

The present system can also be used to measure the wheel alignment of vehicles such as trucks and buses with three or more axles. Six, eight or more wheels can be measured using a single camera bar assembly, and adding extra targets for the additional wheels.

Wheel Alignment System In Conjunction With Vehicle Frame Measurement System

The wheel alignment system disclosed herein can be used in conjunction with an electromagnetic radiation vehicle body measurement system, such as the Brewco™ Wolf system,

disclosed in U.S. Patent Application Serial No. 09/029,139, incorporated herein by reference. In this alternative embodiment, in addition to attaching wheel targets to the vehicle wheels, fixed targets of the type used in the Brewco™ Wolf body measurement system may be attached to the vehicle. The fixed targets used in the Wolf system include a plurality of single-point emitters for attachment to or association with the vehicle frame. The Wolf system includes a camera bar assembly and control and display console of the type preferred in the present invention. The Wolf system also includes a data processor that uses triangulation to find the relative locations of the single-point emitters. Accordingly, the display console of the present invention may be programmed to calculate and display vehicle frame parameters as well as wheel alignment parameters.

The apparatus disclosed herein benefits from the accuracy provided by optical wheel alignment systems yet is not as susceptible to damage or require close to optimum operating conditions, as required by prior art wheel aligners. Because the control and display console requires a minimum of only three points to determine the location and orientation of the wheel targets, only single point emitters are required on the wheel targets for detection by a sensor head. Thus, the wheel targets need not include delicate and bulky parts for providing signals to a sensor. Instead, the wheel targets need support only the emitters and, consequently, may be easily manufactured and be more rugged, lightweight, and easier to handle than prior art wheel targets. Because the locations of only single points need be ascertained by the control and display console, the normal conditions of a vehicle repair shop does not adversely affect the performance of the wheel alignment system and wheel targets at relatively long distances from the camera bar are easily detected. The system may be set up relatively easily and quickly and provide individual wheel run-out measurements as soon as a wheel clamp is mounted on a wheel.

The camera bar of the wheel alignment apparatus of the present invention may be configured to view all of the targets on both sides of the vehicle from a single position. Thus, the operator may view the wheel alignment and suspension system parameters, perform adjustments or repairs, and view the resulting parameters on the display.

While the invention has been particularly shown and described with reference to certain preferred embodiments, it will be understood by those skilled in the art that various alterations and modifications in form and in detail may be made therein without departing from the spirit and scope of the invention.

We claim:

1. An apparatus for measuring at least one vehicle wheel position and stability parameter, comprising:

a wheel clamp securable to a wheel of a vehicle;

a plurality of electromagnetic radiation emitters affixed to said wheel clamp in a predetermined spatial configuration;

a sensor for receiving electromagnetic radiation signals from said plurality of electromagnetic radiation emitters and for providing data signals responsive thereto; and

a processor for receiving said data signals and programmed for calculating at least one wheel position and stability parameter based upon said data signals and said predetermined spatial configuration.

2. The apparatus of claim 1 wherein said plurality of electromagnetic radiation emitters comprises three light emitting diodes affixed to said wheel clamp.

3. The apparatus of claim 1 further including:

a plurality of wheel clamps, each having a plurality of electromagnetic radiation emitters affixed thereto in a predetermined spatial configuration, to be secured to respective wheels of the vehicle; and

wherein said processor is programmed for calculating at least one wheel position and stability parameter for at least two wheels of the vehicle.

4. The apparatus of claim 1 wherein said processor is programmed to generate wheel position and stability parameter display signals based upon said data signals and wherein the vehicle wheel position and stability measuring apparatus further comprises:

a display for receiving said wheel position and stability parameter display signals and displaying at least one wheel alignment parameter.

5. The apparatus of claim 1 wherein said processor is programmed to generate wheel position and stability parameter display signals based upon said data signals and wherein the vehicle wheel position and stability measuring apparatus further comprises:

a display for receiving said wheel position and stability parameter display signals and displaying at least one suspension system condition parameter.

6. The apparatus of claim 1 wherein said sensor comprises a linear camera unit.

7. The apparatus of claim 1 wherein said sensor comprises a two-dimensional array camera.

8. The apparatus of claim 6, further comprising a support bar having an aperture formed thereon, and wherein said linear camera unit resides within said aperture.

9. The apparatus of claim 1 wherein said processor is programmed to calculate relative angular coordinates of said emitters based upon the data signals.

10. The apparatus of claim 1 wherein said processor is programmed to determine a claw normal vector of said wheel based upon the data signals.

11. The apparatus of claim 8 wherein said sensor comprises a plurality of linear camera units.

12. The apparatus of claim 1 wherein said wheel clamp comprises a plurality of rim claws at predetermined positions relative to said plurality of electromagnetic radiation emitters and for attachment to a rim of said wheel.

13. An apparatus for measuring the alignment of motor vehicle wheels comprising a wheel alignment camera for receiving electromagnetic radiation signals from electromagnetic radiation emitters associated with the wheels of a vehicle,

said wheel alignment camera comprising:

a plurality of receptors, wherein each said receptor is comprised of a plurality of pixels;

an electromagnetic radiation shield having a plurality of slits formed therein, wherein each said slit is positioned in proximity to at least one said receptor; and

whereby said wheel alignment camera provides output signals in response to receiving electromagnetic radiation signals.

14. The wheel alignment camera of claim 13 wherein said plurality of receptors comprise first, second, and third receptors and wherein said first and second receptors are oriented in a first direction, and said third receptor is oriented in a second, different, direction.

15. The wheel alignment camera of claim 14 wherein said first and second receptors are horizontally oriented and said third receptor is vertically oriented.

16. The apparatus of claim 13 further comprising a programmable computer for receiving output signals from said wheel alignment camera and wherein said computer is programmed to provide data corresponding to wheel alignment and the condition of suspension system components.

17. A wheel alignment target for use in a wheel alignment system for determining the relative position of a wheel, comprising:

a wheel clamp assembly;

a plurality of electromagnetic radiation emitters affixed to one side of said wheel clamp assembly and arranged in a predetermined configuration.

18. The wheel alignment target of claim 17, wherein said plurality of electromagnetic radiation emitters comprises three electromagnetic radiation emitters.

19. The wheel alignment target of claim 17 further comprising a plurality of rim claws at predetermined positions relative to said plurality of electromagnetic radiation emitters and for attachment to a rim of said wheel.

20. An apparatus for measuring vehicle wheel position and stability parameters comprising:

a camera for receiving electromagnetic radiation signals from electromagnetic radiation emitters associated with the wheels of a vehicle,

said camera comprising:

a camera bar having first and second, spaced apart apertures therein; and

first and second sensors associated respectively with said first and second apertures;

wherein, when said camera is positioned to view said electromagnetic radiation emitters, said camera provides signals responsive to said emitters.

21. The camera of claim 20 wherein said first and said second sensors are each comprised of a plurality of sets of charge coupled devices.

22. The camera of claim 20 wherein said first and said second sensors are each comprised of a plurality of sets of active pixel sensors selected from the group consisting of:

(a) complementary metal-oxide semi-conductors

(b) photodiodes

(c) CIDs

(d) static gate induction transistors

(e) base-stored image sensors

(f) microbolometers

(g) double-gate floating surface transistors

(h) charge modulation devices

(i) bulk charge modulation devices; and

(j) infrared devices.

23. An apparatus for measuring vehicle wheel position and stability parameters, comprising:

a plurality of wheel targets attachable to the wheels of a vehicle;

a plurality of emitters affixed to each of said wheel targets;

a camera bar comprising at least one electromagnetic sensor head, removed from said vehicle wheels and in electromagnetic communication with said targets, for sensing the location of said emitters and providing emitter location signals; and

a processing unit for receiving said emitter location signals, calculating vehicle wheel position and stability parameters, and providing display signals.

24. The apparatus of claim 23 wherein each of said wheel targets further comprises a plurality of target legs.

25. The apparatus of claim 24 wherein each of said wheel targets comprises three target legs.

26. The apparatus of claim 23 wherein said wheel targets are attachable to said vehicle wheels via respective single wheel clamp assemblies.

27. The apparatus of claim 23 wherein said target legs extend outward in three directions substantially 120 degrees apart.

28. The apparatus of claim 23 wherein said emitters comprise light emitting diodes.

29. The apparatus of claim 23 wherein said emitters are controlled by said processing unit.

30. The apparatus of claim 23 wherein said emitters are free running and provide a signal to said processing unit for identifying the source of said emitter location signals.

31. The apparatus of claim 23 wherein each said electromagnetic sensor head comprises a linear camera unit comprised of a plurality of charge coupled devices.

32. The apparatus of claim 23 wherein each said electromagnetic sensor head is comprised of a plurality of sets of active pixel sensors selected from the group consisting of:

(a) complementary metal-oxide semi-conductors
(b) photodiodes
(c) CIDs
(d) static gate induction transistors
(e) base-stored image sensors
(f) microbolometers
(g) double-gate floating surface transistors
(h) charge modulation devices
(i) bulk charge modulation devices, and
(j) infrared devices.

33. The apparatus of claim 23 wherein said camera bar is located to the front of said vehicle.

34. The apparatus of claim 23 wherein said processing unit is programmed to determine at least one vehicle wheel position and stability parameter selected from the group consisting of:

(a) wheel camber

(b) wheel caster

(c) thrust line

(d) geometric center line

(e) steering axis

(f) individual toe

(g) wheel offset

(h) wheel setback

(i) SAI

(j) thrust angle

(k) included angles

(l) axial stability; and

(m) wheel runout

35. A method of determining at least one wheel position and stability parameters of a vehicle wheel, comprising the steps of:

associating with said vehicle wheel at least first, second, and third emitters;

determining first locations of said at least first, second, and third emitters, respectively; and

determining a first position and first orientation of said wheel based upon said determined first locations of said at least first, second, and third emitters.

36. The method of claim 34 further comprising the steps of:

determining a plurality of first emitter planes intersecting said first emitter;

determining a plurality of second emitter planes intersecting said second emitter;

determining a plurality of third emitter planes intersecting said third emitter.

37. The method of claim 35 further comprising the steps of:

rolling said vehicle wheel to a second location;

determining second locations of said at least first, second, and third emitters, respectively;

determining a second position and second orientation of said wheel based upon said determined second locations of said at least first, second, and third emitters;

calculating an axis of rotation of said vehicle wheel;

determining at least one wheel alignment parameter based upon said axis of rotation.

38. The method of claim 37 further comprising the step of displaying said at least one wheel alignment parameter.

39. The method of claim 35 further comprising the step of:

activating said first emitter, said second emitter, and said third emitter in sequential order.

40. The method of claim 37 further comprising the steps of:

rolling said vehicle wheel to a third location;

determining third locations of said at least first, second, and third emitters, respectively;

determining a third position and third orientation of said wheel based upon said determined third locations of said at least first, second, and third emitters; and

ascertaining at least one condition of the suspension system of the vehicle based upon said determined first, second, and third positions and orientations of said wheel.

41. The method of claim 40 further comprising the step of determining and displaying the axial stability of the wheel.

42. The method of claim 37 further comprising the steps of:

determining a first claw normal vector for defining said first position and orientation of said vehicle wheel;

determining a second claw normal vector for defining said second position and orientation of said vehicle wheel; and

calculating a transform matrix for mapping said first claw normal vector to said second claw normal vector.

43. The method of claim 40 further comprising the step of determining a third claw normal vector for defining the third position and orientation of said wheel.

44. A method of determining the caster angle of vehicle wheel, comprising the steps of:
associating with said vehicle wheel at least first, second, and third emitters;
turning said wheel to the right;
measuring a first caster angle target plane;
turning said wheel to the left;
measuring a second caster angle target plane;
determining the caster angle of said wheel based upon said first and second caster angle target planes.

45. A method of identifying the relative location of a point on a wheel, comprising the steps of:
attaching an emitter to the wheel;
providing emitter signals;
detecting said emitter signals;
providing emitter position signals based upon said detected emitter signals;
calculating the position of said emitter based upon said emitter position signals.

46. A method for measuring the alignment of the wheels of a motor vehicle, comprising:
positioning a plurality of emitters in a predetermined array on a motor vehicle wheel;
detecting signals generated by said emitters; and
processing detected signals for determining the position and orientation of said wheel and for providing wheel alignment data.

47. The method of claim 46 further comprising the step of emitting pulses of electromagnetic radiation from said plurality of emitters in sequential order.

48. The method of claim 46 wherein said signals generated by said emitters comprise identifiable wavelengths, said method further comprising the step of identifying an emitter based upon the wavelength of an emitted signal.

49. The method of claim 46 further comprising the step of determining first and second claw normal vectors of said wheel while said wheel is at first and second locations, respectively.

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FIG. 1

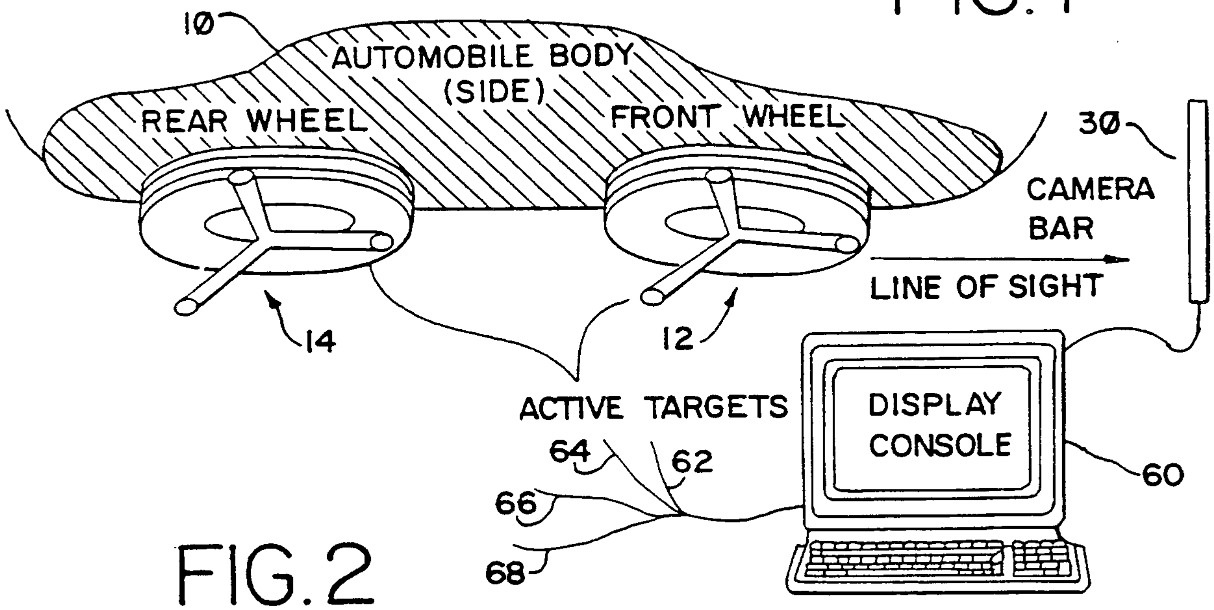


FIG. 2

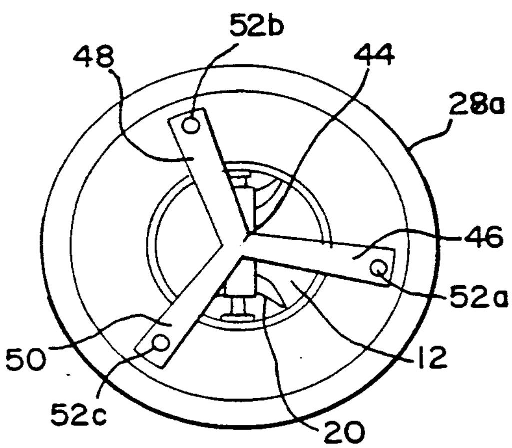


FIG. 4

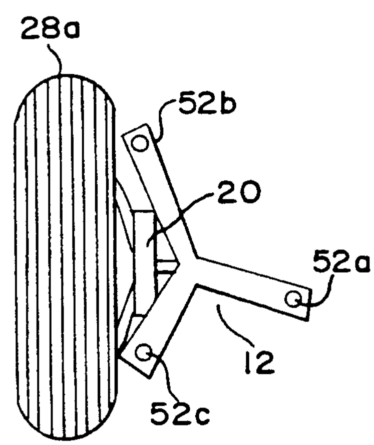
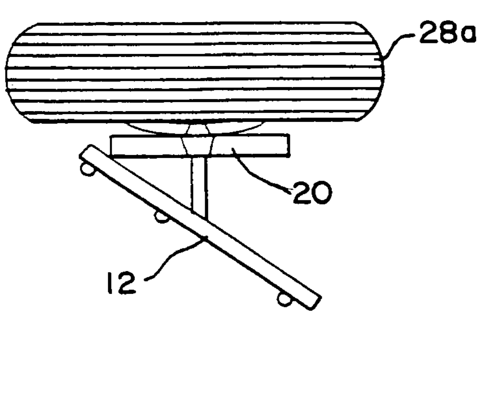


FIG. 3



SUBSTITUTE SHEET (RULE 26)

FIG. 5

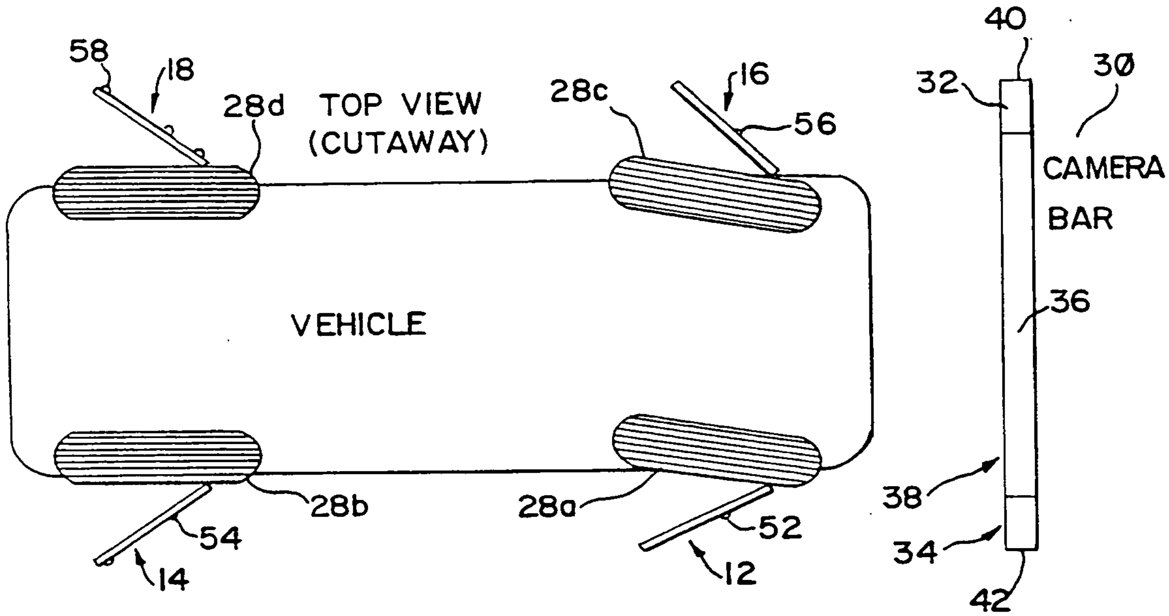
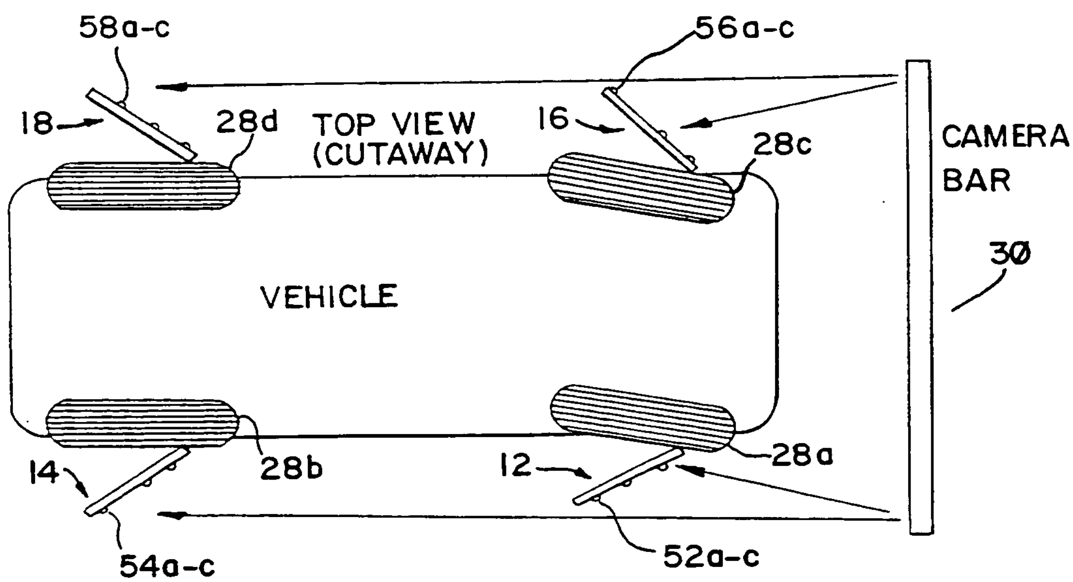

58
18
28d
TOP VIEW
(CUTAWAY)
28c
16
56
40
32
30
CAMERA
BAR
VEHICLE
36
38
34
42
28b
54
14
28a
52
12

FIG. 6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BAR
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28b
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28a
54a-c
52a-c

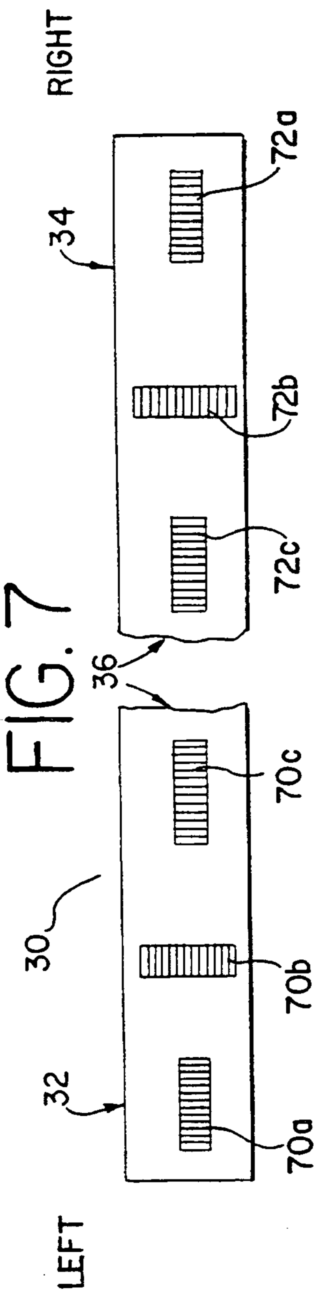


FIG. 7

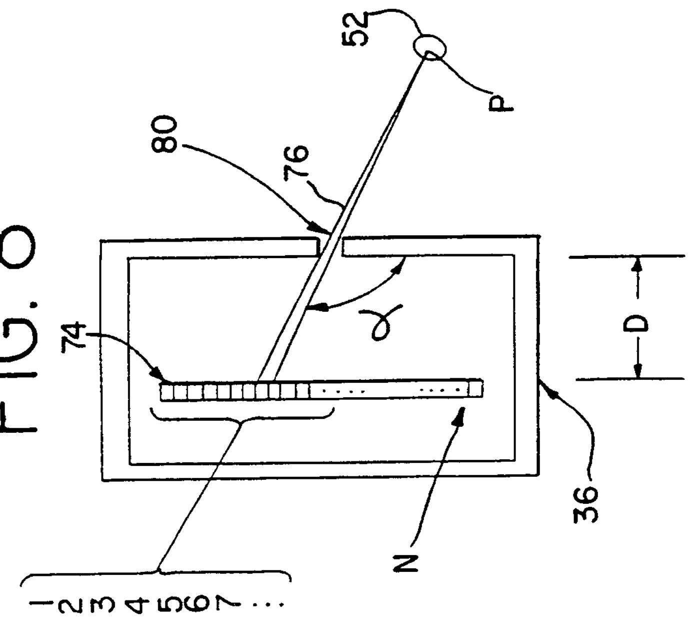


FIG. 8

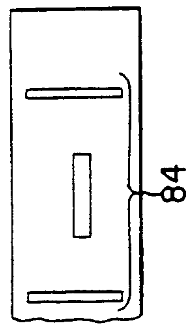


FIG.9b

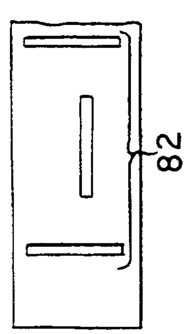


FIG.9a

FIG. 10

FRONT			
CASTER	3.1°	0.3°	2.7°
CAMBER	1.1°	0.1°	1.0°
TOE	0.01°	0.10°	0.09°
REAR			
CAMBER	0.4°	-0.2°	0.6°
TOE	0.16°	-0.24°	-0.40°
THRUST ANGLE		0.3°	
FRONT DIAGNOSTICS			

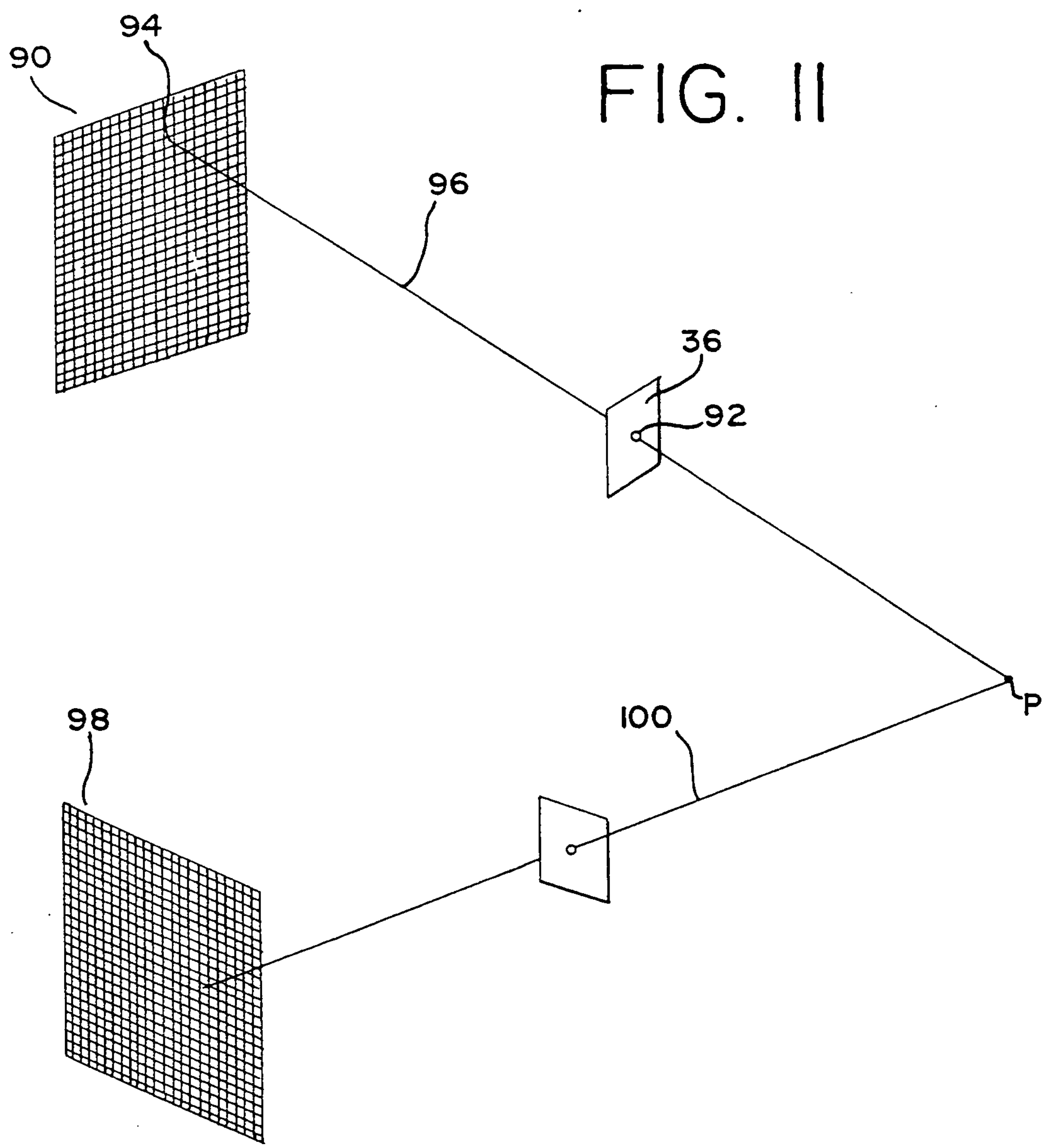


FIG. 11

FIG. 12

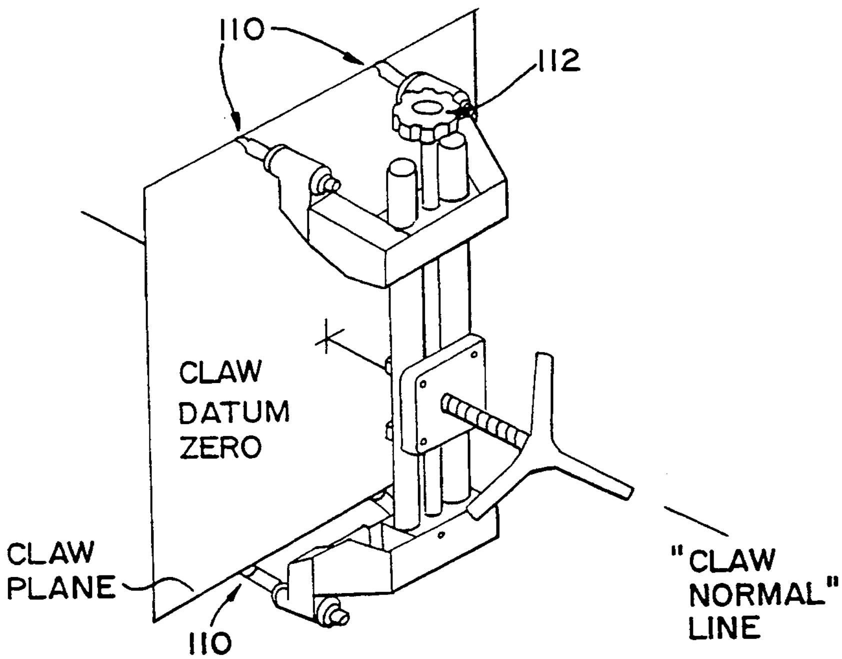

110
112
CLAW
DATUM
ZERO
CLAW
PLANE
110
"CLAW
NORMAL"
LINE

FIG. 13

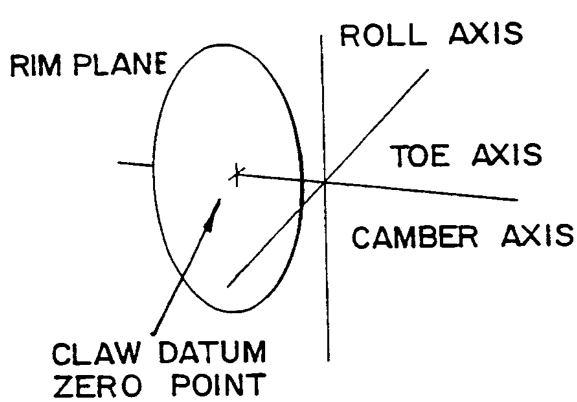

RIM PLANE
ROLL AXIS
TOE AXIS
CAMBER AXIS
CLAW DATUM
ZERO POINT

FIG. 14

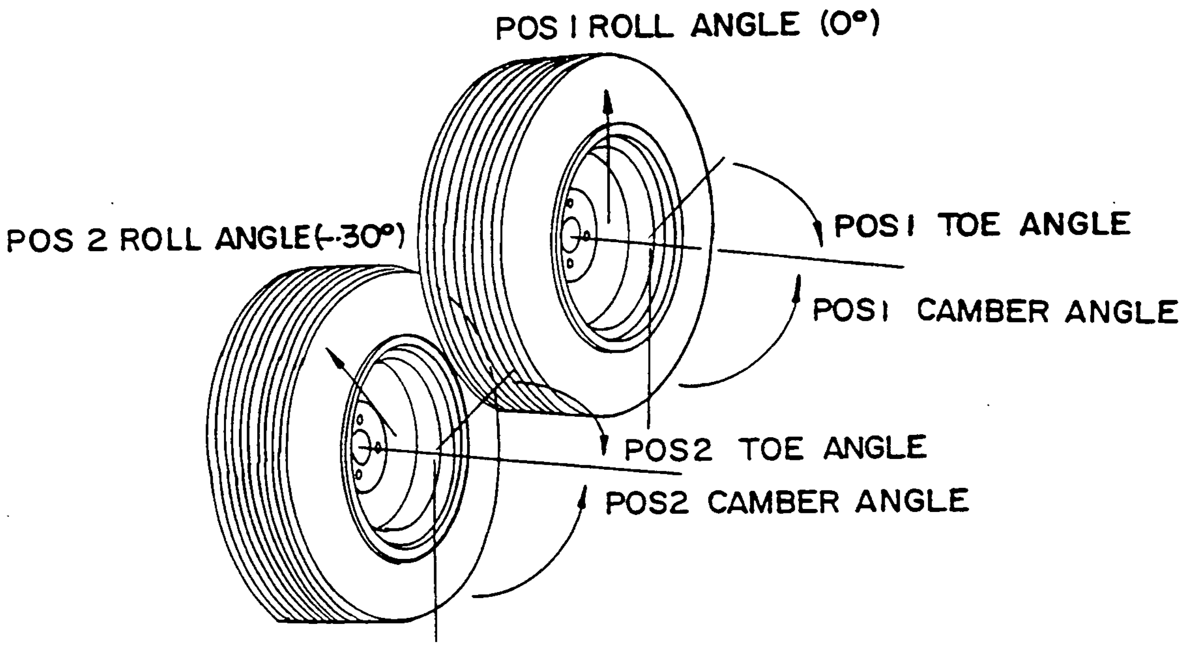
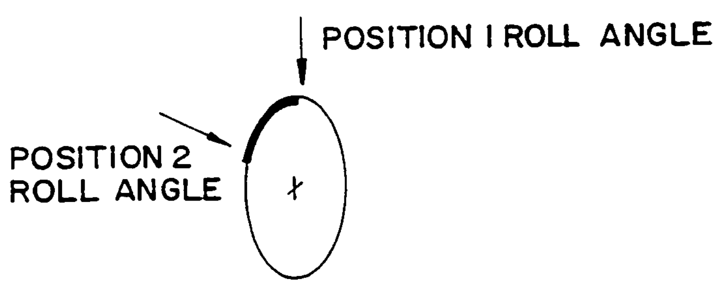


FIG. 15



 SUBSTITUTE SHEET (RULE 26)

FIG. 16

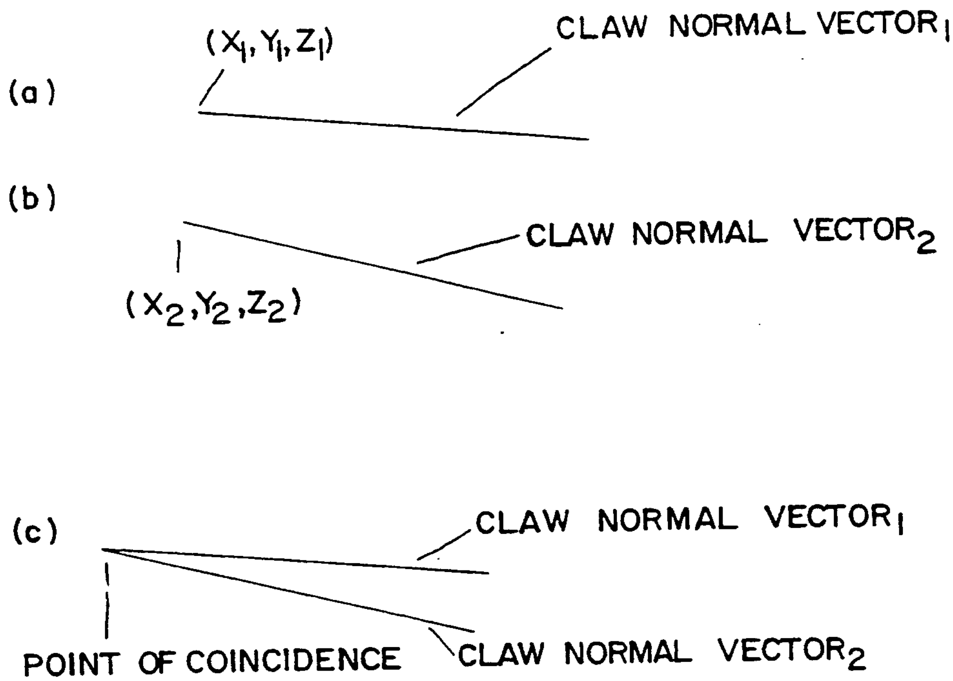
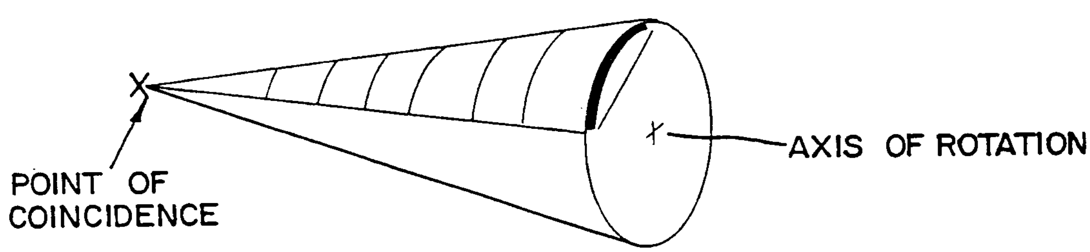

(a)
(X_1, Y_1, Z_1)
CLAW NORMAL VECTOR$_1$
(b)
CLAW NORMAL VECTOR$_2$
(X_2, Y_2, Z_2)
(c)
CLAW NORMAL VECTOR$_1$
POINT OF COINCIDENCE
CLAW NORMAL VECTOR$_2$

FIG. 17


POINT OF
COINCIDENCE
AXIS OF ROTATION

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 00/13279

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5724743 A	10-03-1998	US 5535522 A	16-07-1996
		AU 711728 B	21-10-1999
		AU 7442596 A	30-04-1997
		CA 2232534 A	17-04-1997
		DE 880677 T	06-05-1999
		EP 0880677 A	02-12-1998
		JP 11513789 T	24-11-1999
		WO 9714016 A	17-04-1997
		US 5809658 A	22-09-1998
		US 5969246 A	19-10-1999
		US 5943783 A	31-08-1999
		AU 669211 B	30-05-1996
		AU 4846993 A	29-03-1994
		CA 2143844 A,C	17-03-1994
		EP 0674759 A	04-10-1995
		JP 2936114 B	23-08-1999
		JP 8501155 T	06-02-1996
		WO 9405969 A	17-03-1994
US 5781286 A	14-07-1998	EP 0774646 A	21-05-1997
US 5675515 A	07-10-1997	US 5724128 A	03-03-1998
		AU 3210297 A	09-12-1997
		EP 0840881 A	13-05-1998
		WO 9744635 A	27-11-1997
		US 5870315 A	09-02-1999
US 4534115 A	13-08-1985	NONE	
EP 874217 A	28-10-1998	DE 19717569 A	29-10-1998
		JP 10307003 A	17-11-1998

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INTERNATIONAL SEARCH REPORT

In ational Application No
PCT/US 00/13279

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 675 515 A (JANUARY DANIEL B) 7 October 1997 (1997-10-07) cited in the application abstract; figure 5	44
A	US 4 534 115 A (KASHUBARA DAN) 13 August 1985 (1985-08-13) column 2; figures 1,3,5	1,2
A	EP 0 874 217 A (HOFFMAN WERKSTATT-TECHNIK GMBH) 28 October 1998 (1998-10-28) abstract; figure 1	1

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/13279

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01B11/275

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 724 743 A (JACKSON BERNIE FERGUS) 10 March 1998 (1998-03-10) cited in the application	1-9,11, 12, 17-19, 23,26, 28,33, 35,44-46
	abstract; figures 1-3,9 column 11 -column 12 ---	
X	US 5 781 286 A (KNESTEL ANTON) 14 July 1998 (1998-07-14) abstract; figures 4-6 column 8 -column 9	13
A	---	8,20
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
20 July 2000	01/08/2000

Name and mailing address of the ISA	Authorized officer
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